On Linking the Impacts and Effects of Wildland Fires to Their Behavior

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ABSTRACT

There are many descriptors or characteristics of free-burning wildland fire behavior that relate to five distinct impact zones: (i) around the flames; (ii) below the flames; (iii) in the flames; (iv) above the flames; and (v) behind the flames. These include, but are not limited to, flame front dimensions (length, height and depth), linear rate of advance, fireline intensity, flaming residence and smouldering or burn-out times, and type of fire (ground, surface, crown). Such descriptors determine the immediate physical or acute impacts of fire which give rise to ecological effects. For example, the temperature profile in the thermal or convective plume above a surface fire will dictate the height of crown scorch that in turn determines the probability of tree mortality. To further illustrate the prospects for biophysical fire effects modelling, the case of serotinous cone opening in jack pine and lodgepole pine forests will be examined in this seminar presentation.

Quinney College of Natural Resources Seminar Series, Utah State University, Logan, UT, October 31, 2012

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Marty Alexander, PhD, RPF

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Background of Presenter

- Fought first wildland fire in CO as a 15-year old
- Member of USFS WY Interagency Hotshot Crew, summers of 1972 & 1973
- Worked part-time for USFS National Fire Danger Rating System Project, 1972-1974
- USFS fuel inventory – Selway-Bitterroot Wilderness, 1975
- BSc (CSU), MSc (CSU) and PhD (ANU) degrees in forestry
- Employed by Canadian Forest Service in fire behavior research, 1976-2010
- Additional work experience in Australia, New Zealand, Alaska, Portugal, Italy, Turkey

Consider myself a "student of wildland fire"

Fire is a "Pervasive" Force

(**pervasive** – tending to pervade or spread throughout)

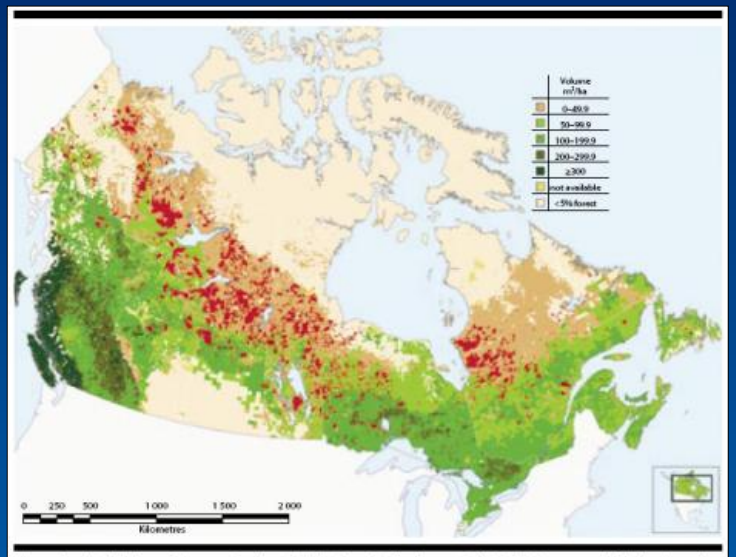
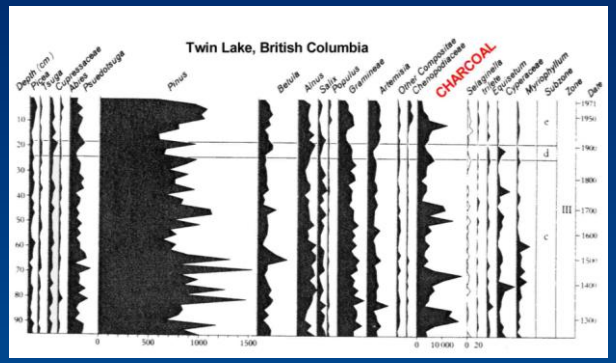
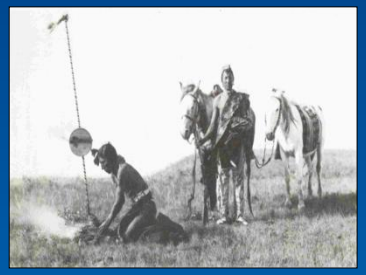
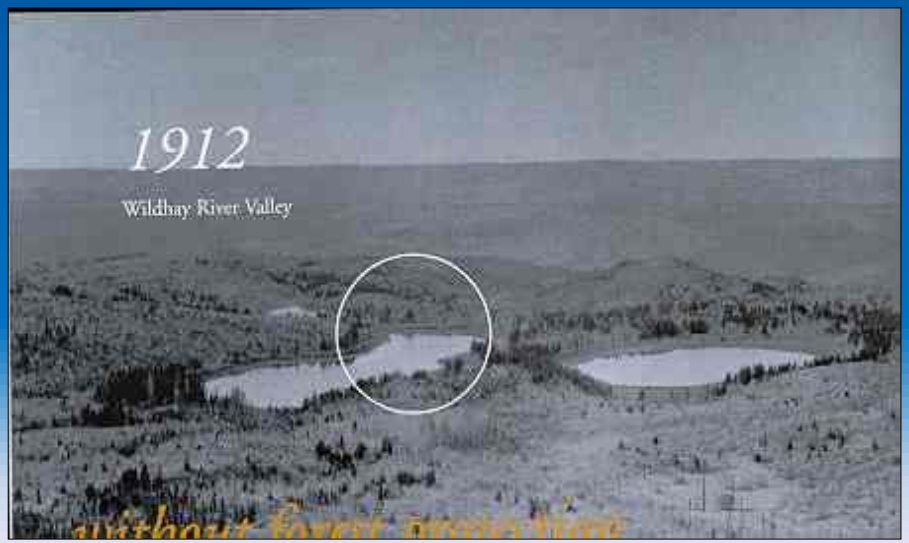


Figure 1. Distribution of fires greater than 200 hectares (red polygons), 1980–2001 as recorded in the Canadian Large Fire Database (Stocks et al. 2002) with respect to mature forest volume in Canada's National Forest Inventory (Gillis 2001).



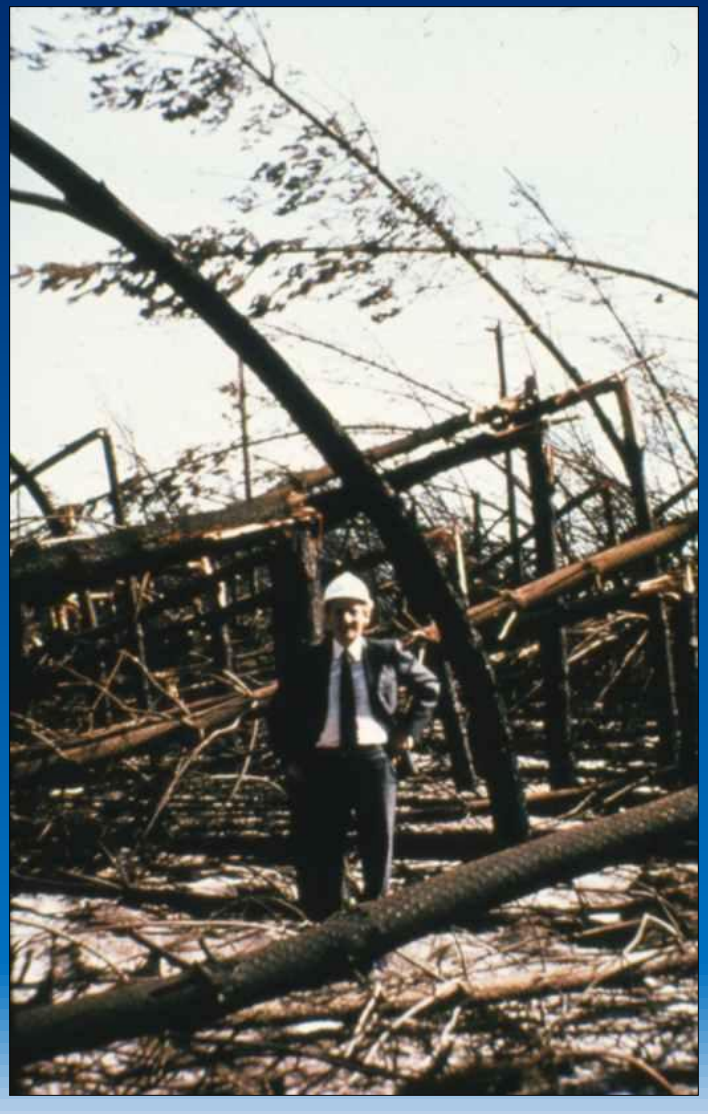




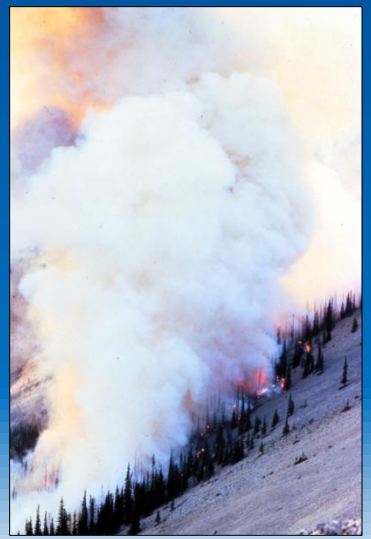
Why are wildland fires significant?

Suppression Expenditures

Community Protection



Firefighter Safety



Use of Fire

Resource Damages & Impacts

1910 Fires in the Northern Rockies:

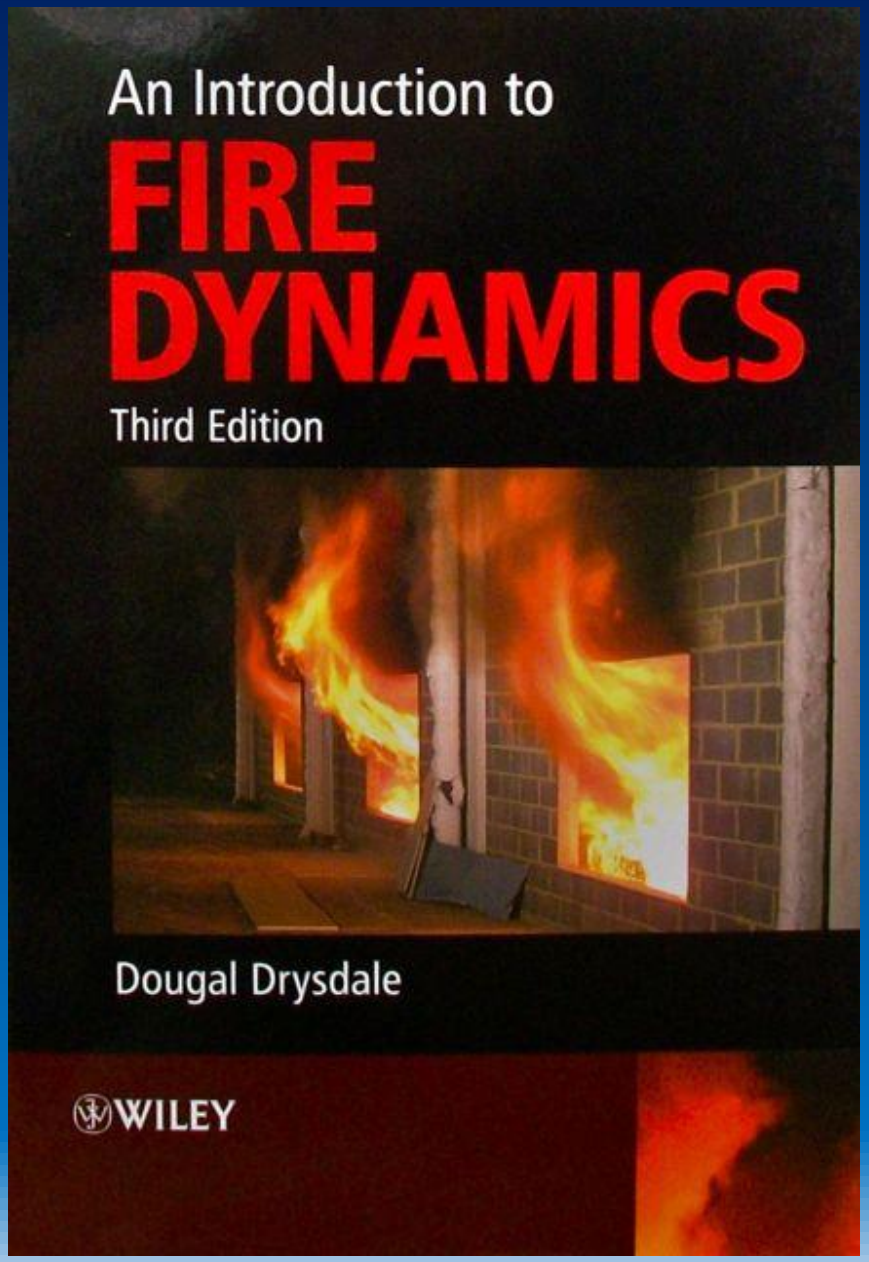
The Year the Mountains Roared

(78 Fatalities)

The War Eagle Mine in northern Idaho, where Ranger Edward Pulaski and his crew of 42 men rode out the "Big Blowup" of August 20–21, 1910. Photo: J.B. Halm, Forest Service.

2012 Waldo Canyon Fire, Colorado

(2 fatalities)



... further major advances in combating wildfire are unlikely to be achieved simply by continued application of the traditional methods.

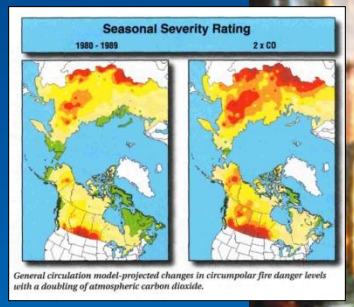
What is required is a more fundamental approach which can be applied at the design stage ...

Such an approach requires a detailed understanding of fire behaviour ...

Drysdale (2011)

Future Challenges:

there's no lack of them!



General circulation model-projected changes in circumpolar fire danger levels with a doubling of atmospheric carbon dioxide.

Crown Fire Potential in Mountain Pine Beetle Attacked Stands

Salt Fire - August 2011
Salmon-Challis National Forest, Idaho

http://www.youtube.com/watch?v=KKpBqdf16rE

Roles of Fire as an Ecological Process:

(from Wright and Heinselman 1973)

- Fire influences the physical-chemical environment
- Fire controls plant species and communities
- Fire regulates dry-matter production and accumulation
- Fire determines wildlife habitat patterns and populations
- Fire influences insects, parasites, fungi, etc.
- Fire controls major ecosystem processes and characteristics

Fire's Dichotomous Role

Fire can have many beneficial purposes. On the other hand, it may actually be damaging, depending on the time of year and the fire's behavior. For example:

Fire Can:	Or it May:
1. Reduce flammable fuels	- Eventually increase fire hazards
2. Remove organic matter	- Contribute more
3. Expose mineral soil	- Permit it to erode
4. Kill viable seeds in duff	- Stimulate germination
5. Kill understory species	- Cause their roots to sprout
6. Reduce insect numbers	- Enhance insect environment
7. Kill pathogens	- Provide entry for fungi

Fire Behavior Defined

The manner in which fuel ignites, flame develops, fire spreads and exhibits other related phenomena as determined by the fire environment.

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.

Fire Environment Factors

Fuel Characteristics:

- Quantity
- Moisture
- Size & Shape
- Depth/Height
- Arrangement

Weather Elements:

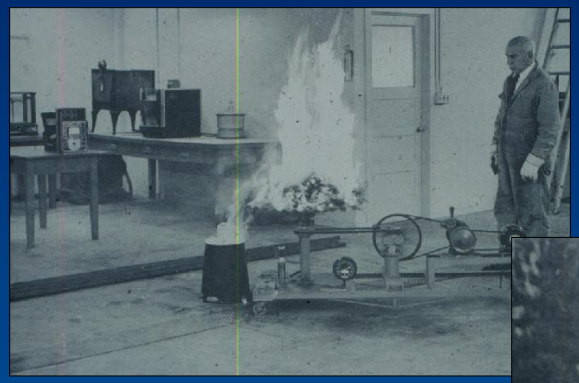
- Wind Speed & Direction
- Relative Humidity
- Air Temperature
- Rainfall Amounts & Duration
- Cloud Clover
- Atmospheric Instability

Topographic Features:

- Slope Steepness & Aspect
- Elevation
- Configuration
- Barriers to Fire Spread

Formative Years of Fire Behavior Research: Field

Formative Years of Fire Behavior Research: Lab



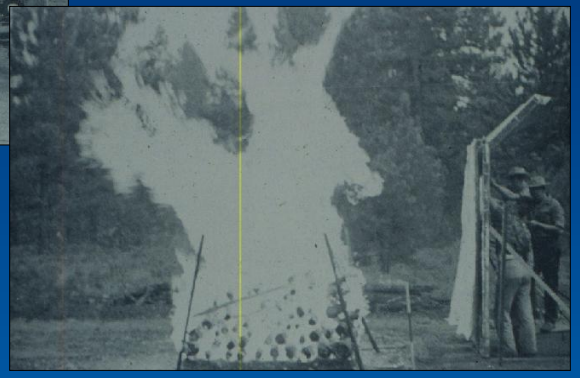


FIGURE 3.—Wind tunnel used in fire-behavior studies; test section is 30 feet long with a cross section 6 x 6 feet, over-all length 55 feet.

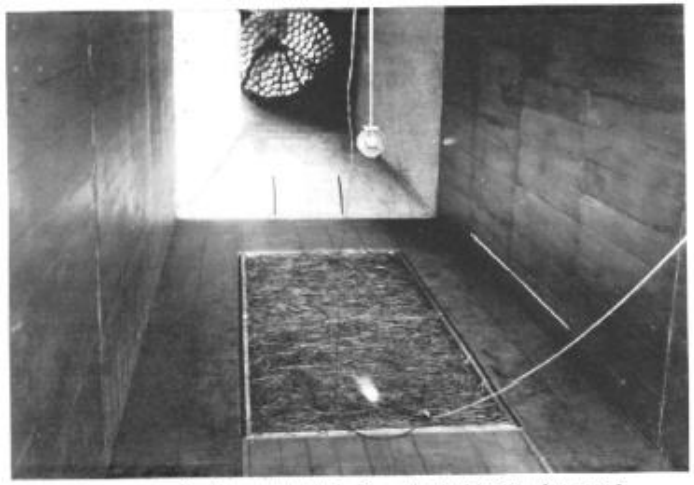


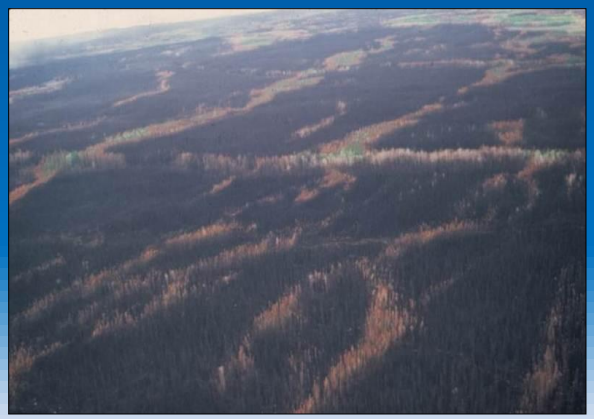
FIGURE 4.—Position of initial ignition of a fuel bed in the tunnel.

Modern Era of Fire Behavior Research: Field

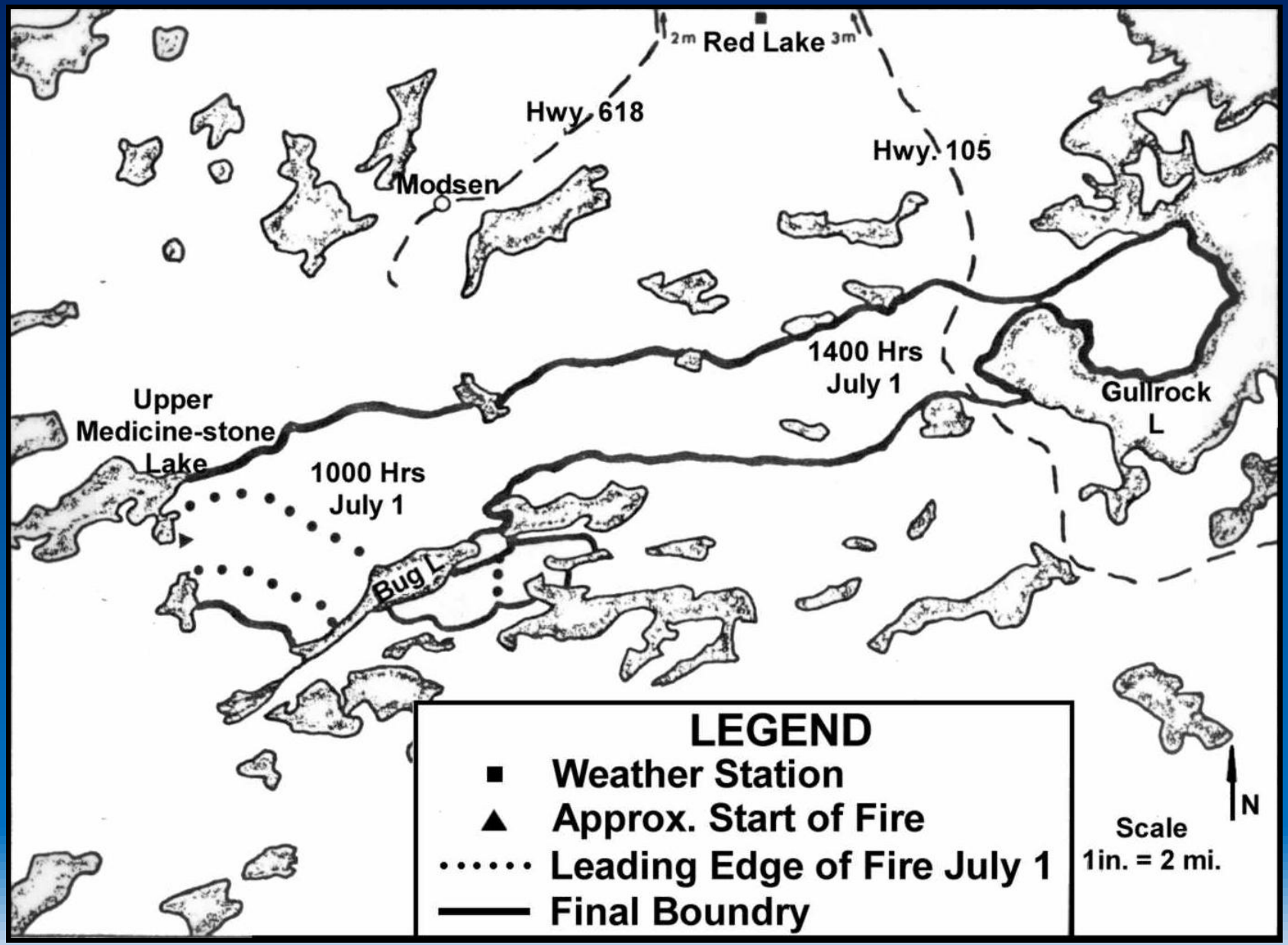
Modern Era of Fire Behavior Research: Lab

Stages of Wildfire Observation and Documentation

- Detection
- Initial attack
- Later stages of suppression
- After containment

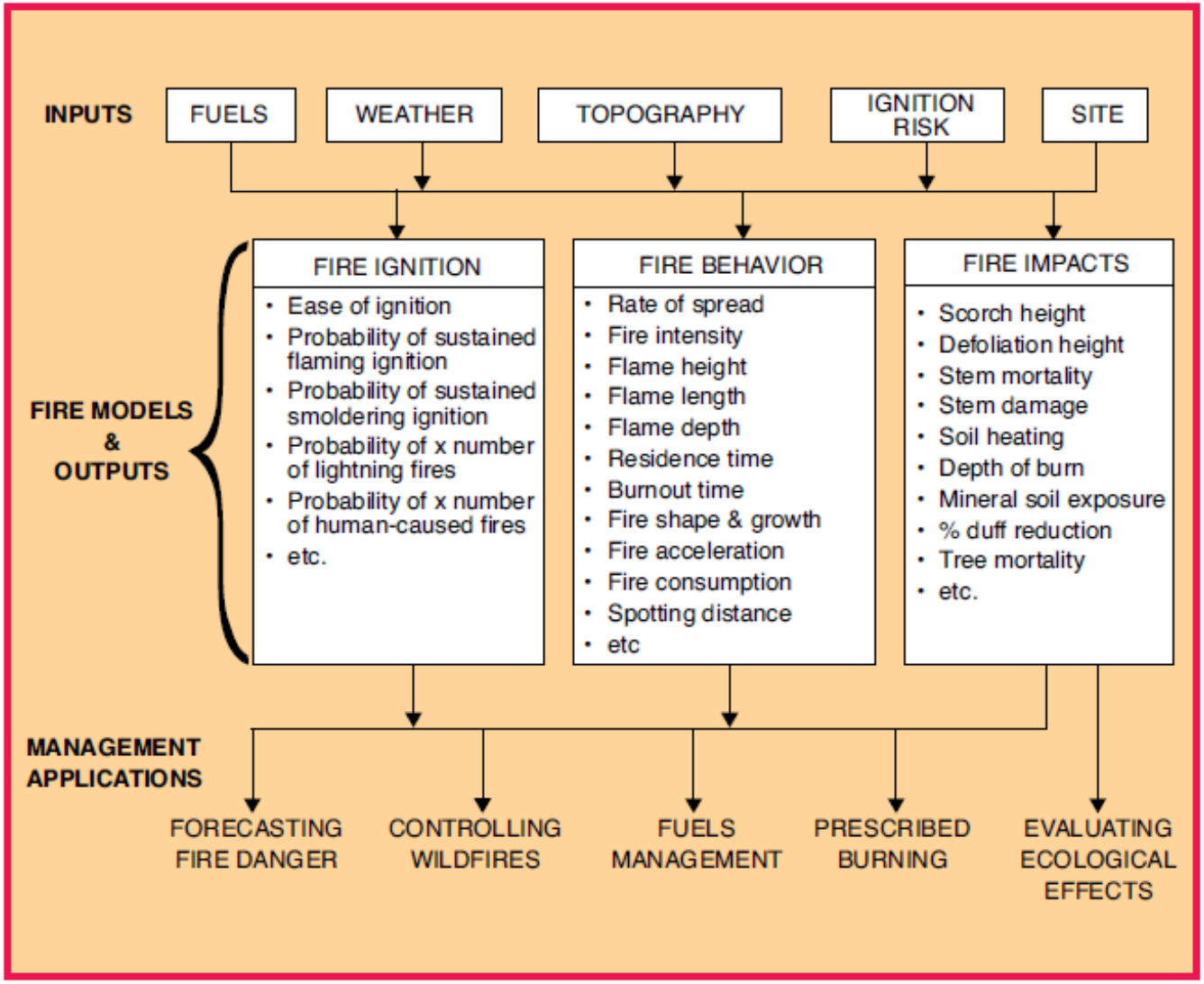


Red Lake 35-61 Fire - Northern Ontario



Fire Progress Map

Conceptual Model of Scientifically-based Wildland Fire Management



The "Two Solitudes" in Wildland Fire Behavior Research

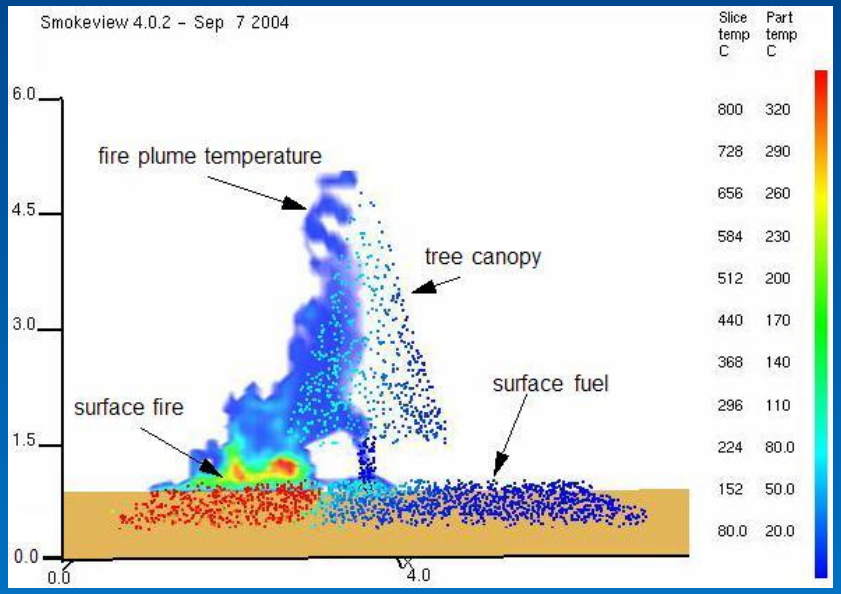
Empirical Approach

versus

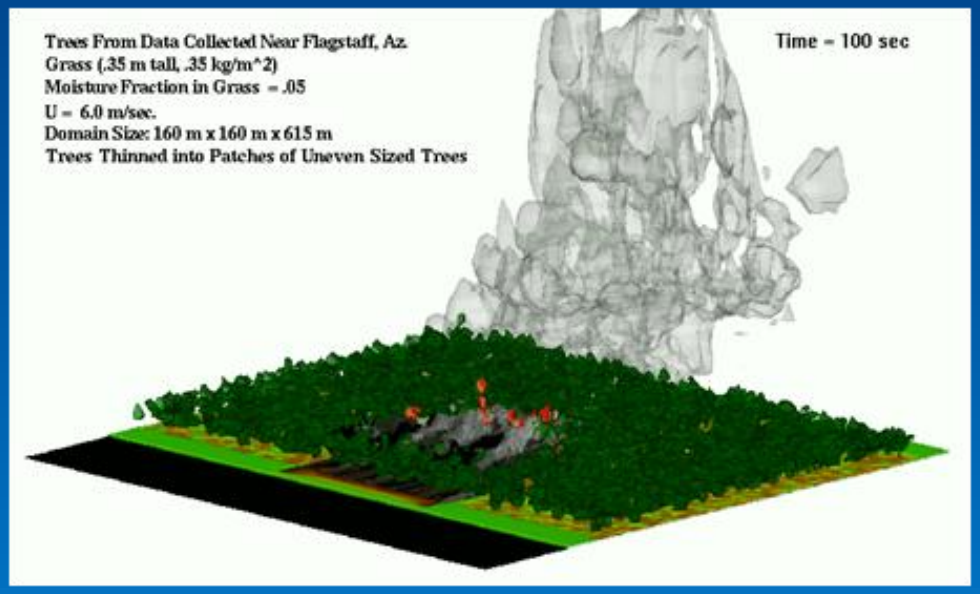
Physical/Theoretical Approach

Physics-based Fire Behavior Simulators

WFDS

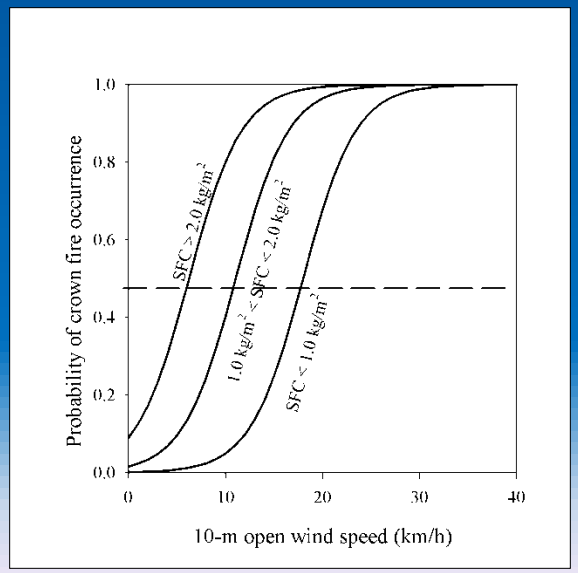


FIRETEC



The most effective means of judging potential fire behavior is considered to be the coupling of (1) <u>mathematical modelling</u> with (2) <u>experienced judgement</u> (e.g., "expert opinion"), and (3) published <u>case study knowledge</u> (e.g., wildfires and operational prescribed fires)

1



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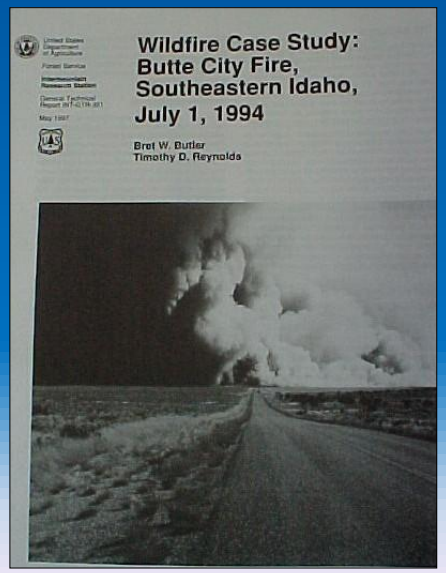
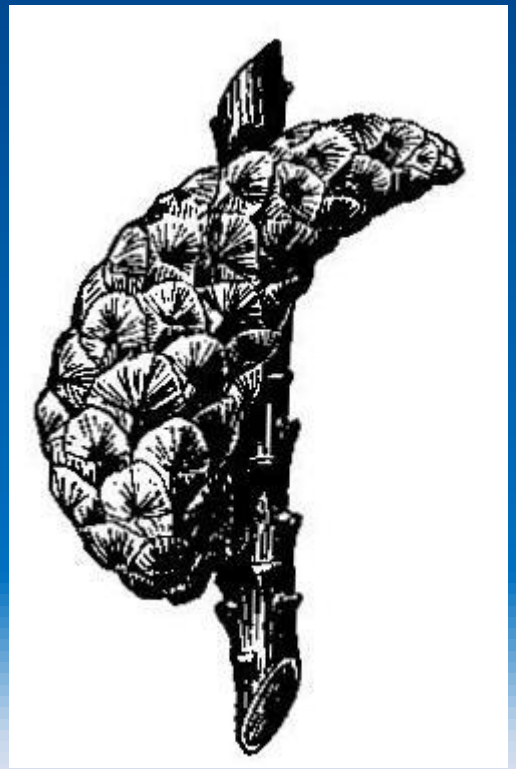


What kind of fire behavior is required to open serotinous cones of jack pine and lodgepole pine?

Serortinous cones of jack pine and lodgepole pine:

sealed shut by a resinous bond at the tips of the cone scales require high temperatures for them to open

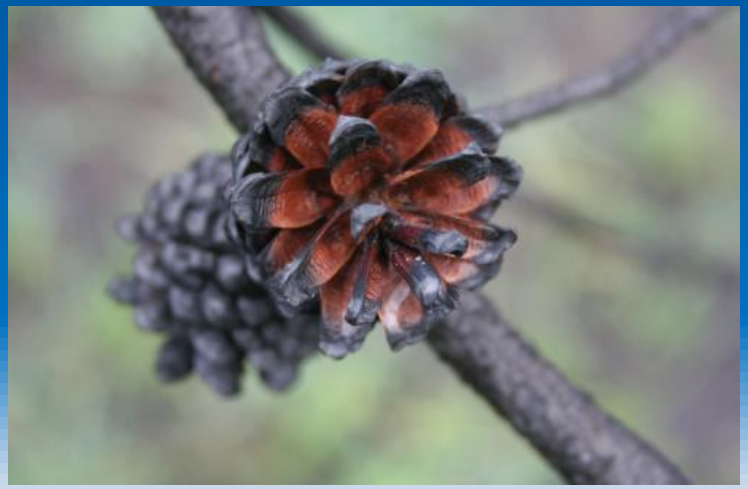
HEAT

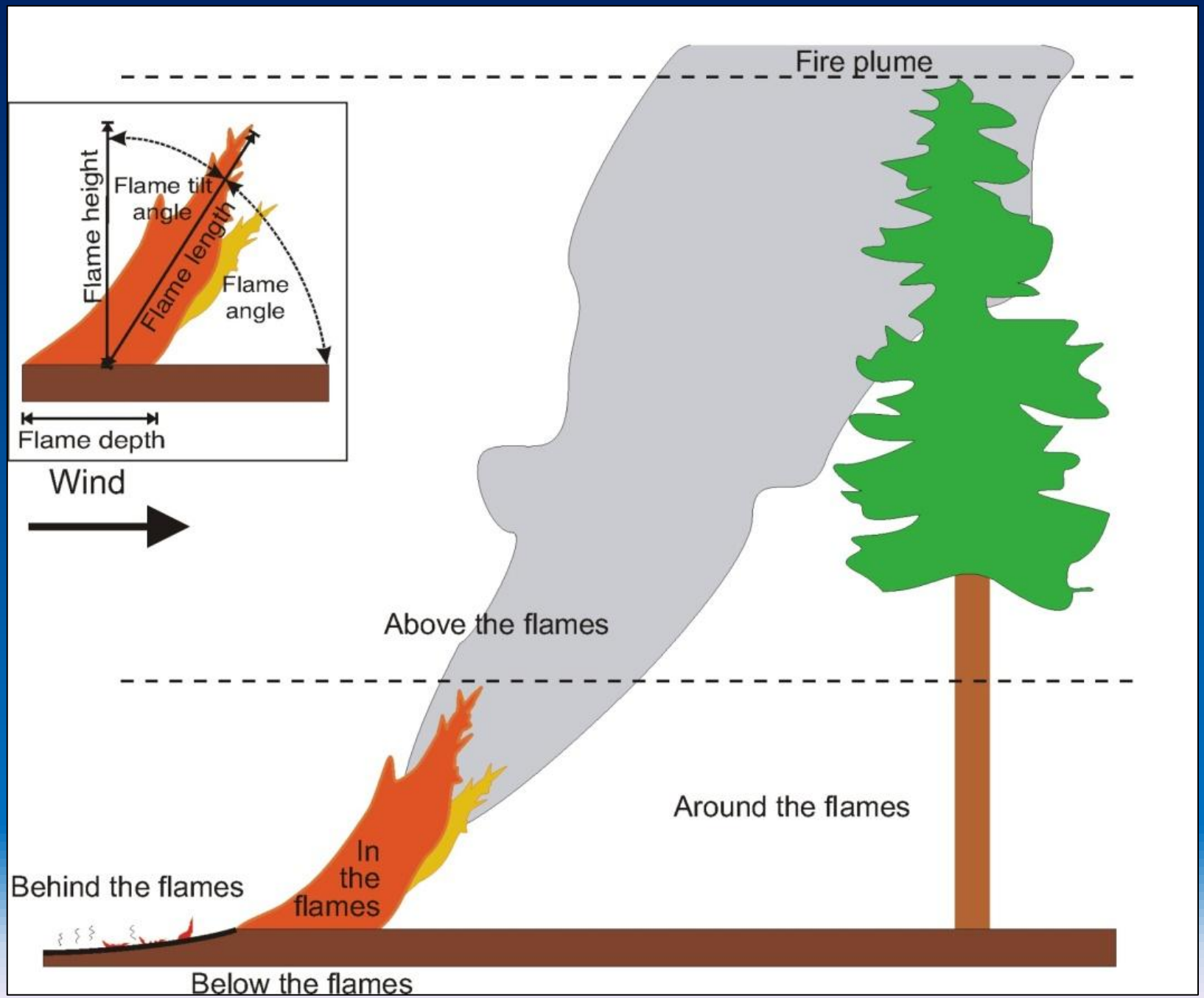


Focus of Present Study:

Develop a simple method for determining the conditions associated with the melting of the resinous bonding material found on serotinous cones of jack pine and lodgepole pine in relation to quantifiable fire behavior.

Examine impact of cone ignition or charring on seed viability in relation to crown fire behavior.




Fire plume
Flame height
Flame tilt angle
Flame length
Flame angle
Flame depth
Wind
Above the flames
Around the flames
In the flames
Behind the flames
Below the flames

Basic Features of a Forest of Wildland Fire:

It spreads but it also …

consumes or "eats" fuel and …

it produces heat energy and light in …

… a visible flaming combustion reaction.

Basic descriptor of a spreading heat source:

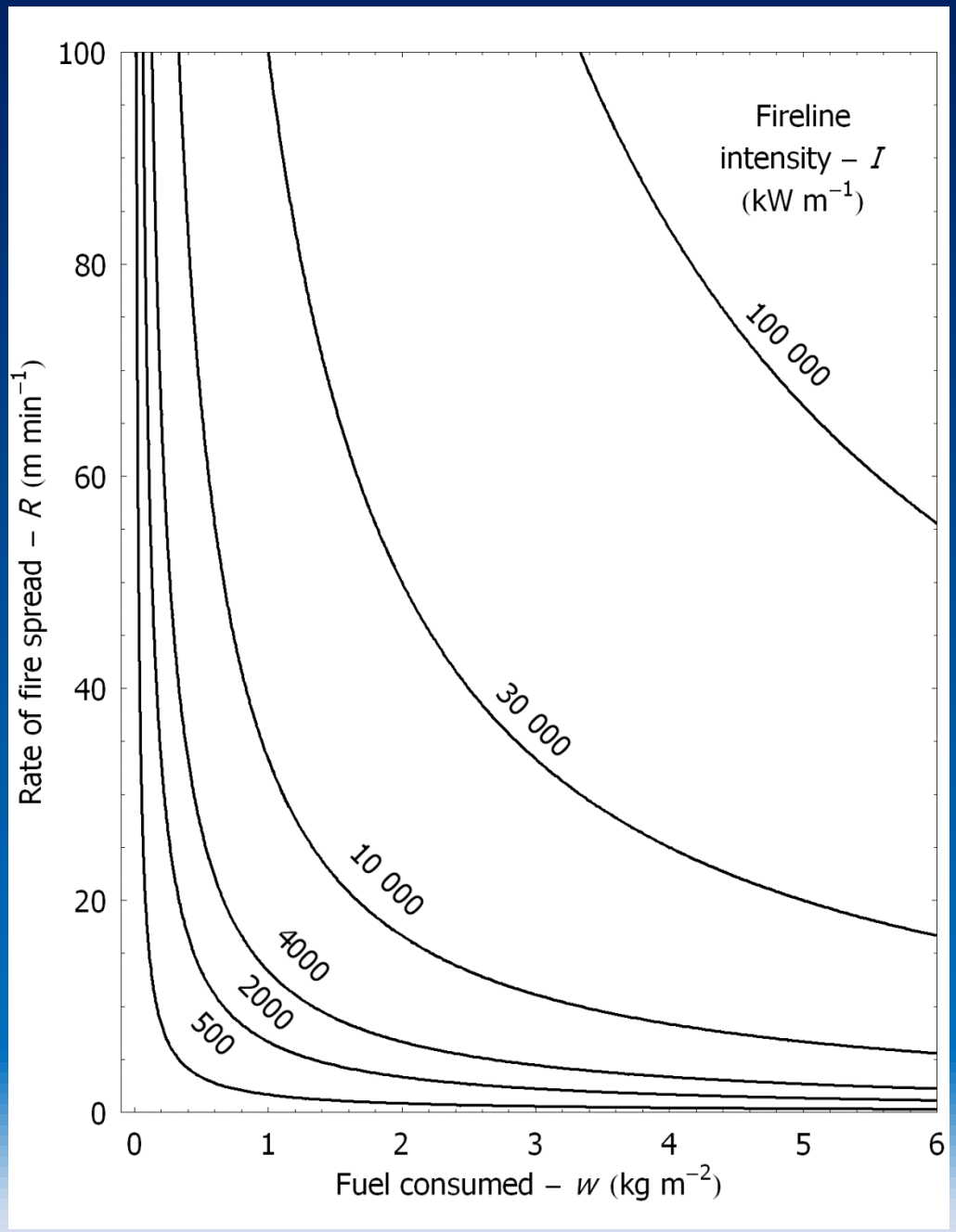
$$I = H \cdot w \cdot r$$

I – Byram's (1959) fireline intensity (kW m^{-1})

H – Net low heat of combustion (~18 000 kJ kg^{-1})

w – Fuel consumed in active flaming front (kg m^{-2})

r – Linear rate of fire spread (m s^{-1})



Fire behavior characteristics chart

Onset of crowning:

- 5-10 m min^{-1}
- >4000 kW m^{-1}

Continuous active crowning:

- 15-30 m min^{-1}
- >10 000 kW m^{-1}

Convective heating of the overstory canopy by surface fire:

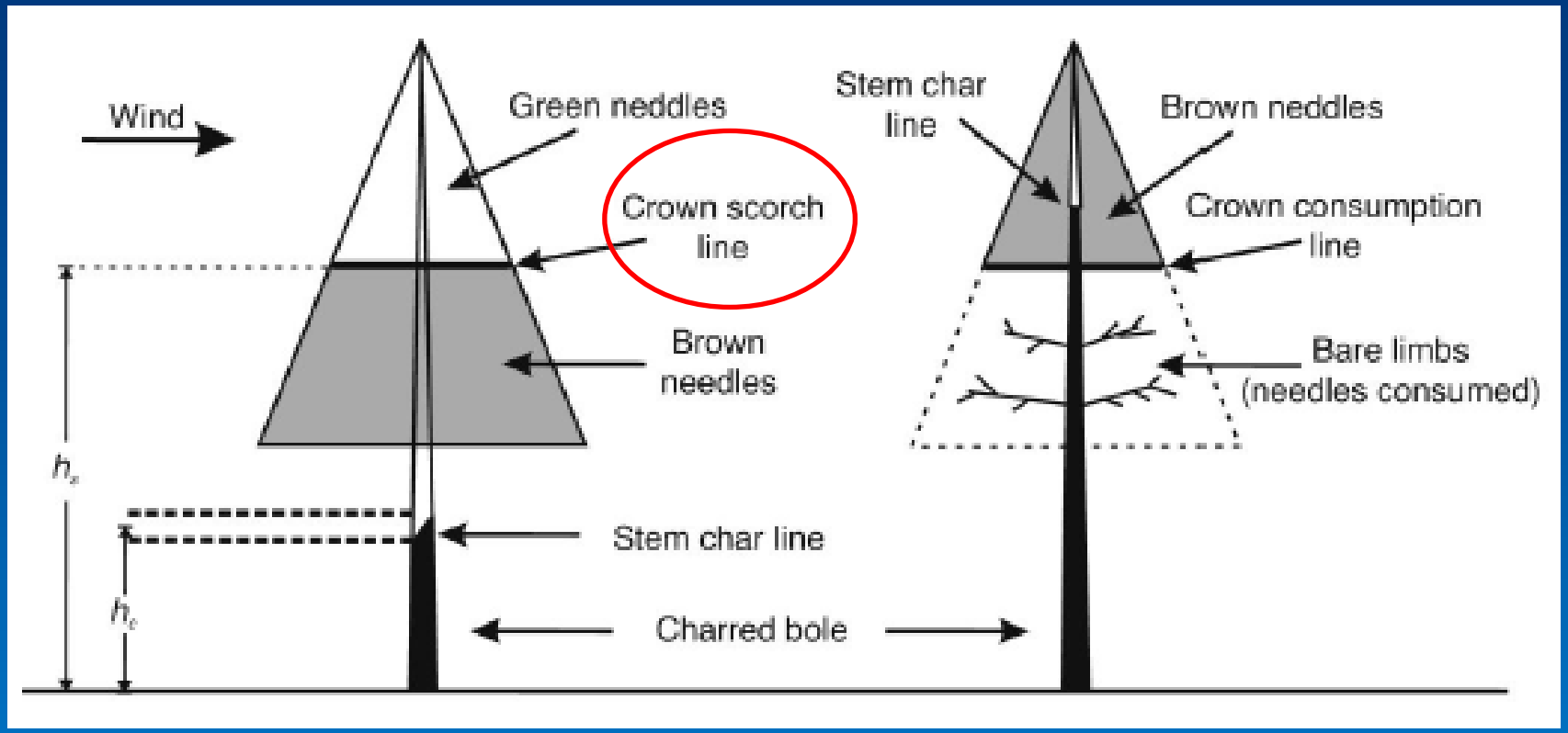
$$\Delta T = \frac{3.85 \cdot I^{2/3}}{z}$$

ΔT – Temperature rise above ambient air at z (°C)

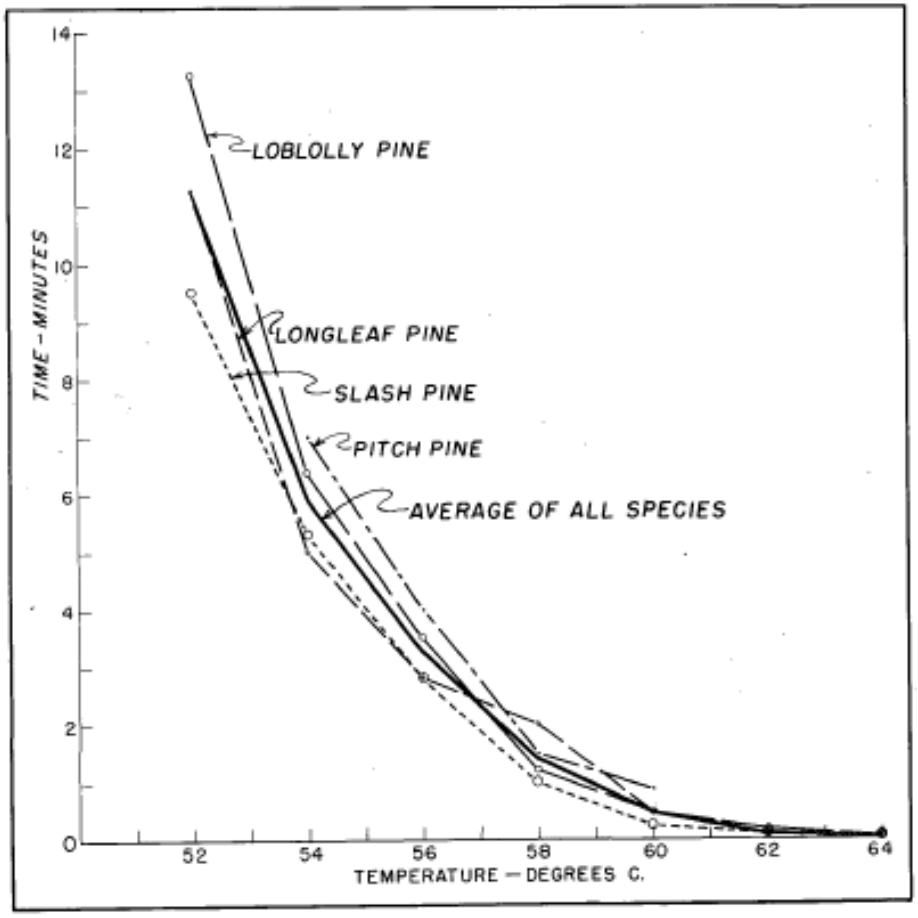
I – Byram's (1959) fireline intensity (kW m^{-1})

z – Height above ground (m)

Crown scorch height



Crown scorch height:
temperature of 57-60 ºC is maintained for ~1.0 min

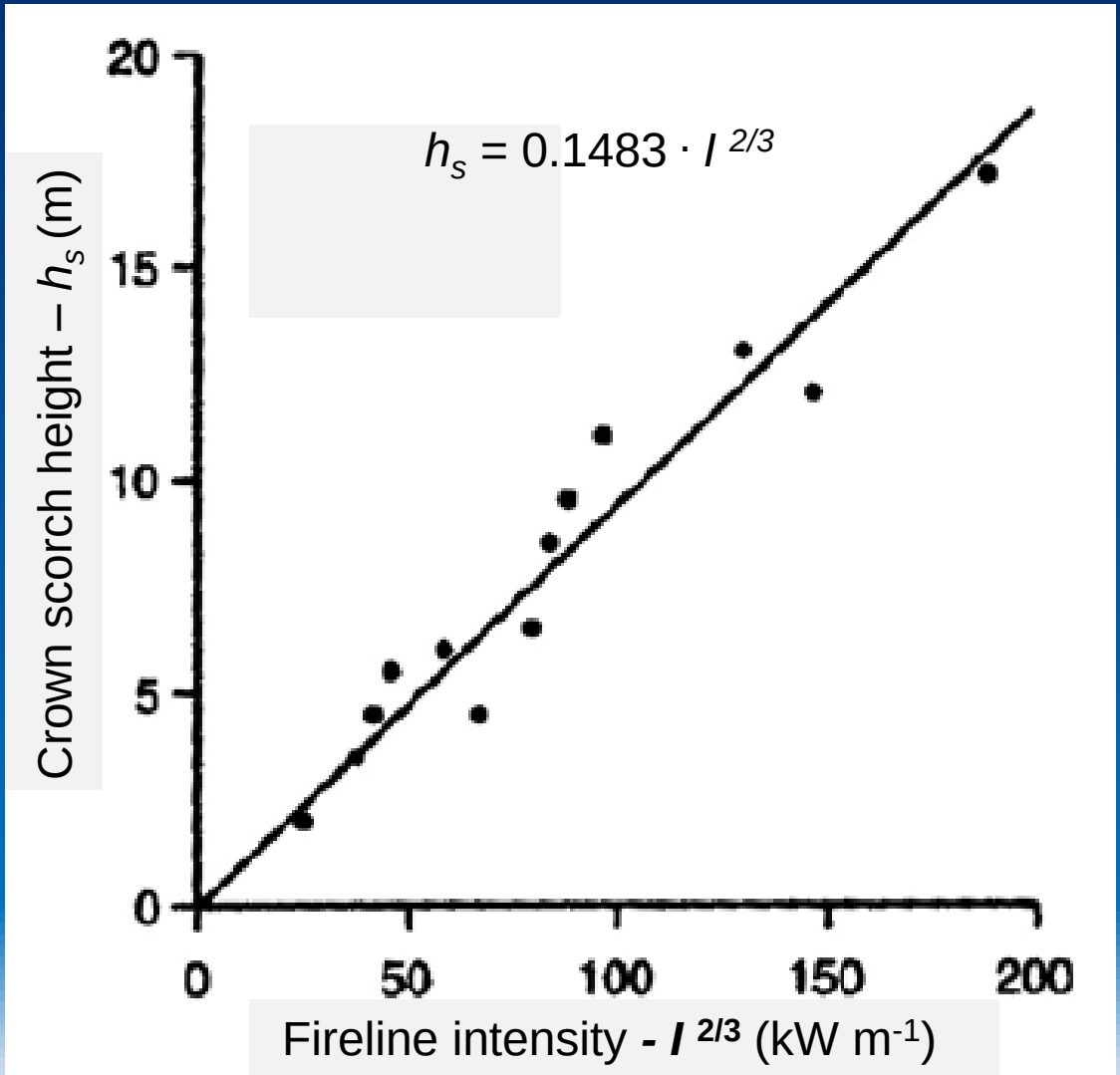


Killing temperatures for southern pine needles when immersed in a water bath.

Byram & Nelson (1952)

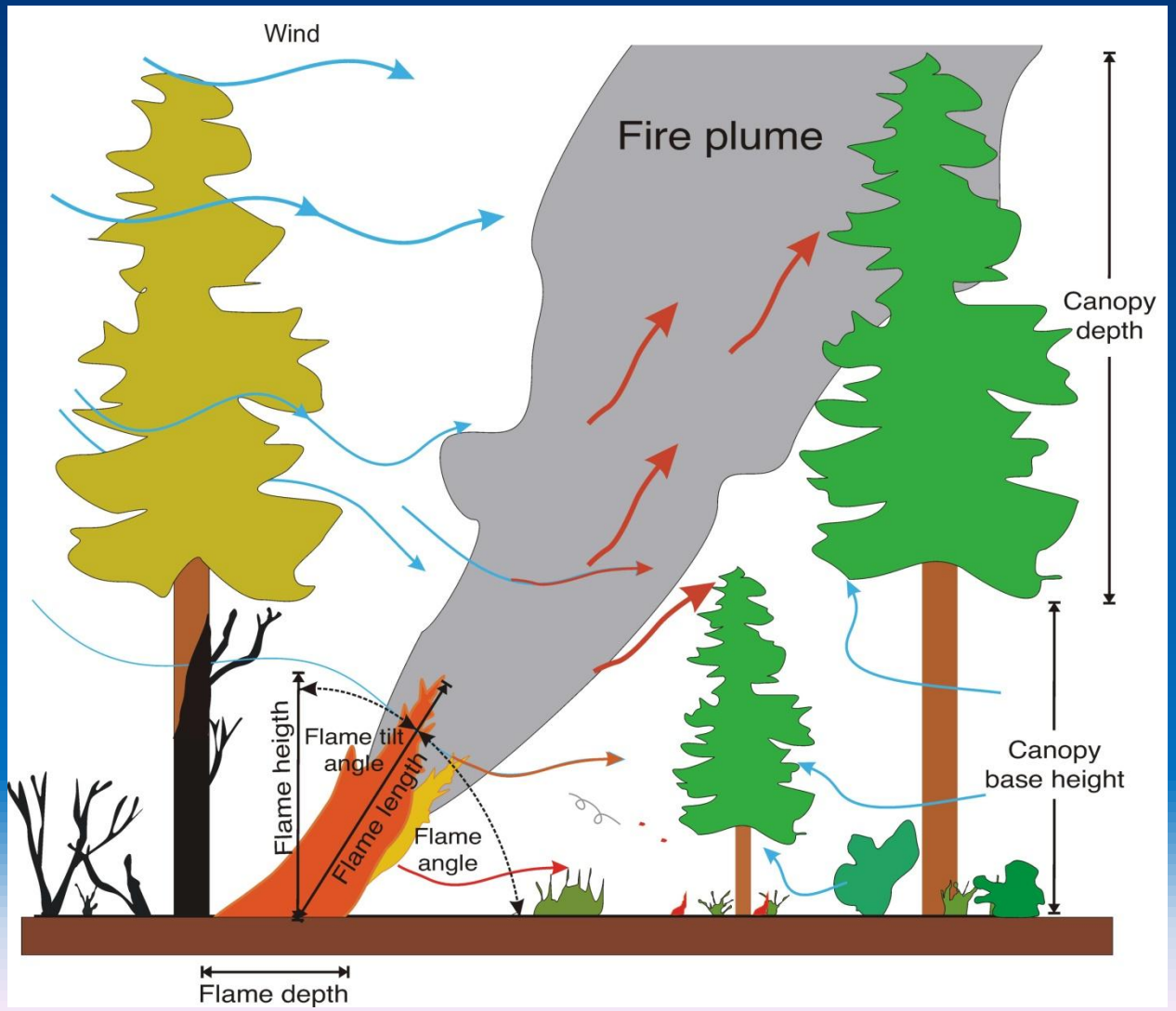
Van Wagner (1973)
crown scorch height – fireline intensity model

Ambient Air Temperatures: 23.5 to 31 °C



In-stand winds: 2.3 to 4.7 km h^{-1}

Duration of convective heating by surface fire



Flame front residence time:

Represents the length of time it takes for the flame zone to pass a given point.

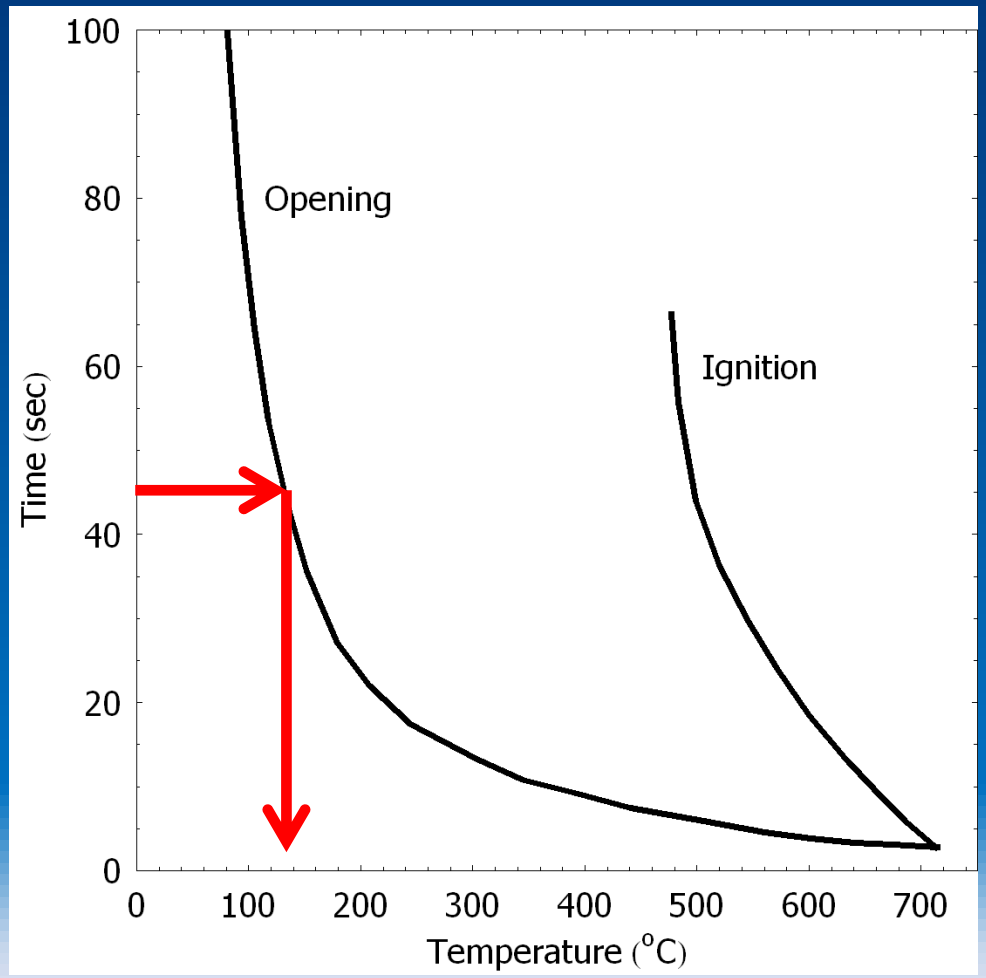
Numerically, the flame front residence time (***t_r*** , min) equal to the horizontal flame depth (***D***, m) of a spreading fire divided by the fire's rate of advance (***R***, m min^{-1}):

$$t_r = D \div R$$

Surface fires in jack pine & lodgepole pine stands typically produce t_r values of 0.5 to 1.0 min

Time-temperature dependency relationships

Given t_r values of 0.5 to 1.0 min, the corresponding temperatures would vary from 112 to 168 °C.



Open muffle oven study

Beaufait (1960)

Heating in the muffle oven is primarily by radiation while in a forest fire plume, it is primarily by convection.

Crown fire considerations

Start

Spread

Crown Fire Initiation – Van Wagner (1977)

Criteria: surface fire $I \geq I_o$

$$I_o = (0.010 \cdot CBH \cdot (460 + 25.9 \cdot FMC))^{1.5}$$

I_o – Critical surface fire intensity needed for initial crown combustion (kW m^{-1})

CBH – Canopy base height (m)

FMC – Foliar moisture content (% oven-dry weight basis)

Van Wagner (1977) – Crown Fire Propagation

Criteria: $R \geq R_o$ for active crown fires
$R < R_o$ for passive crown fires

$$R_o = \frac{3.0}{CBD}$$

R_o – Critical minimum spread rate for active or fully developed crowning (m min^{-1})

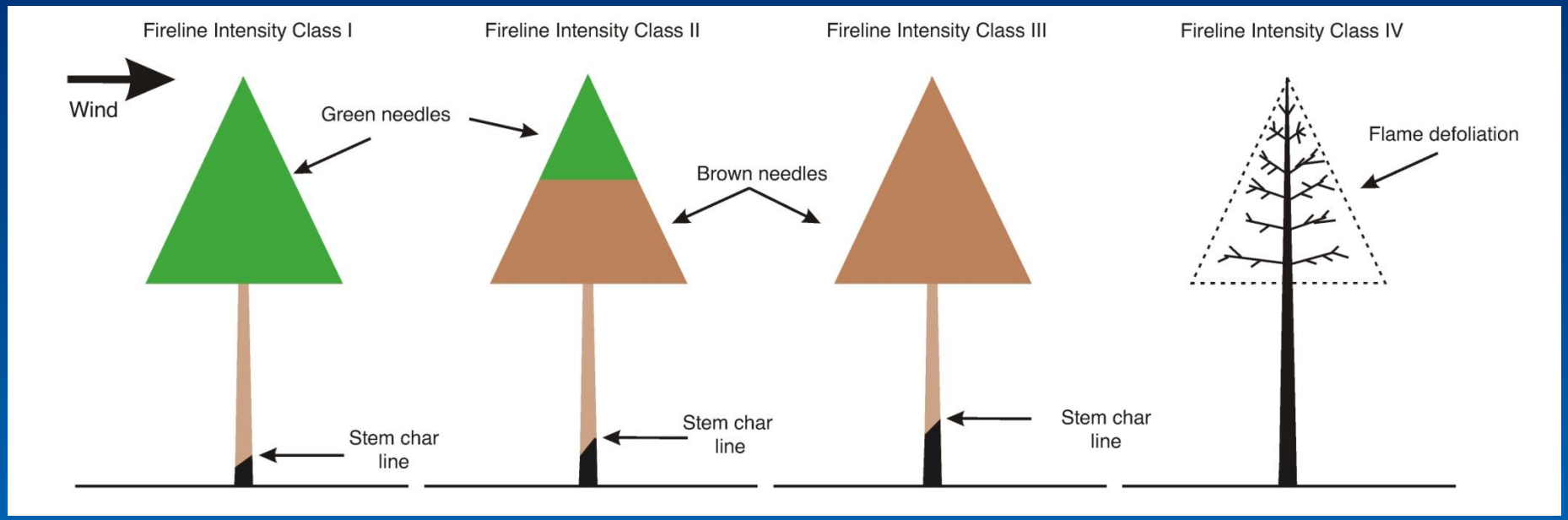
CBD – Canopy bulk density (kg m^{-3})
(*CBD* = canopy fuel load ÷ live crown length)

Canopy Flame Front Residence Times

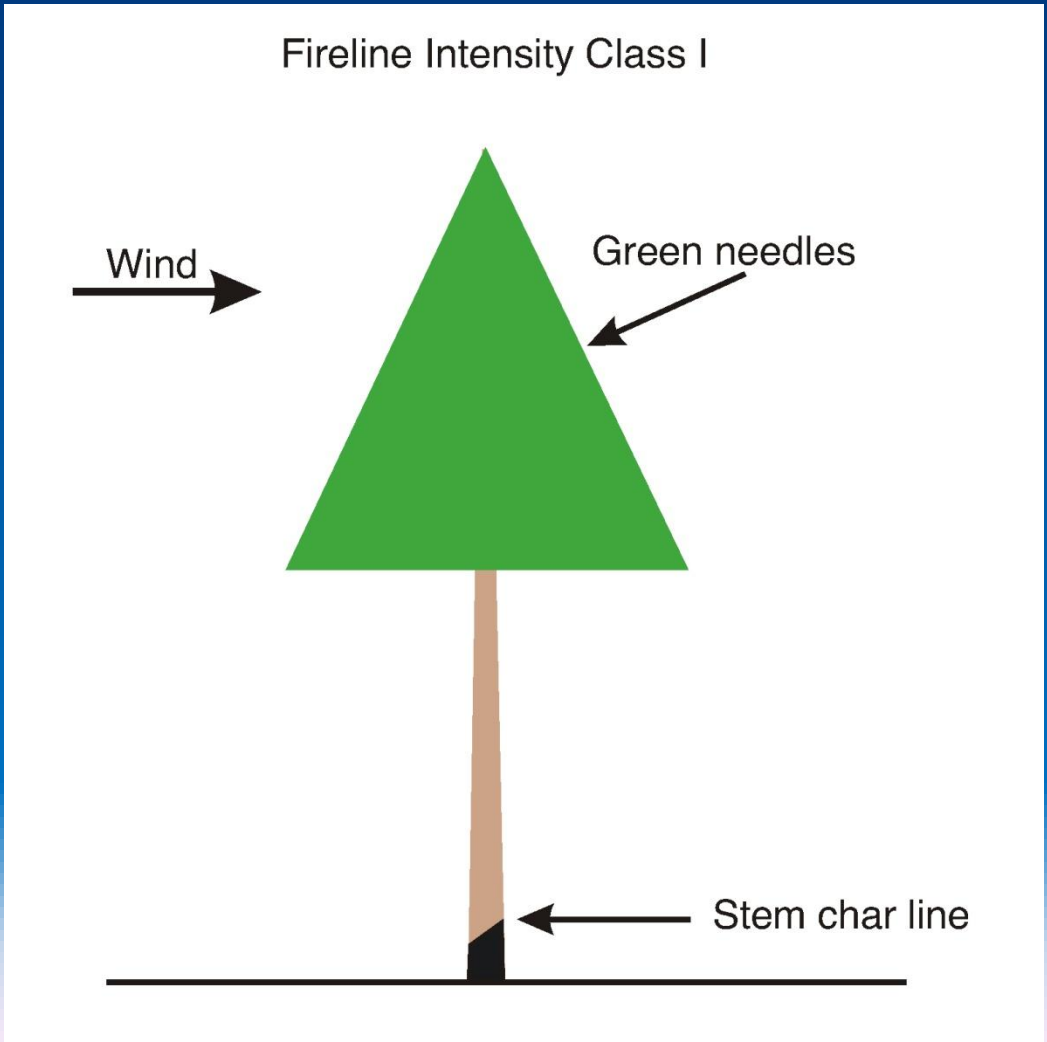
t_r at the ground surface vs. t_r in the live canopy ~ 2.5: 1 ratio

Post-burn mosaic of canopy fire impact types

Four categories of canopy fire impact and cone opening or lack thereof:

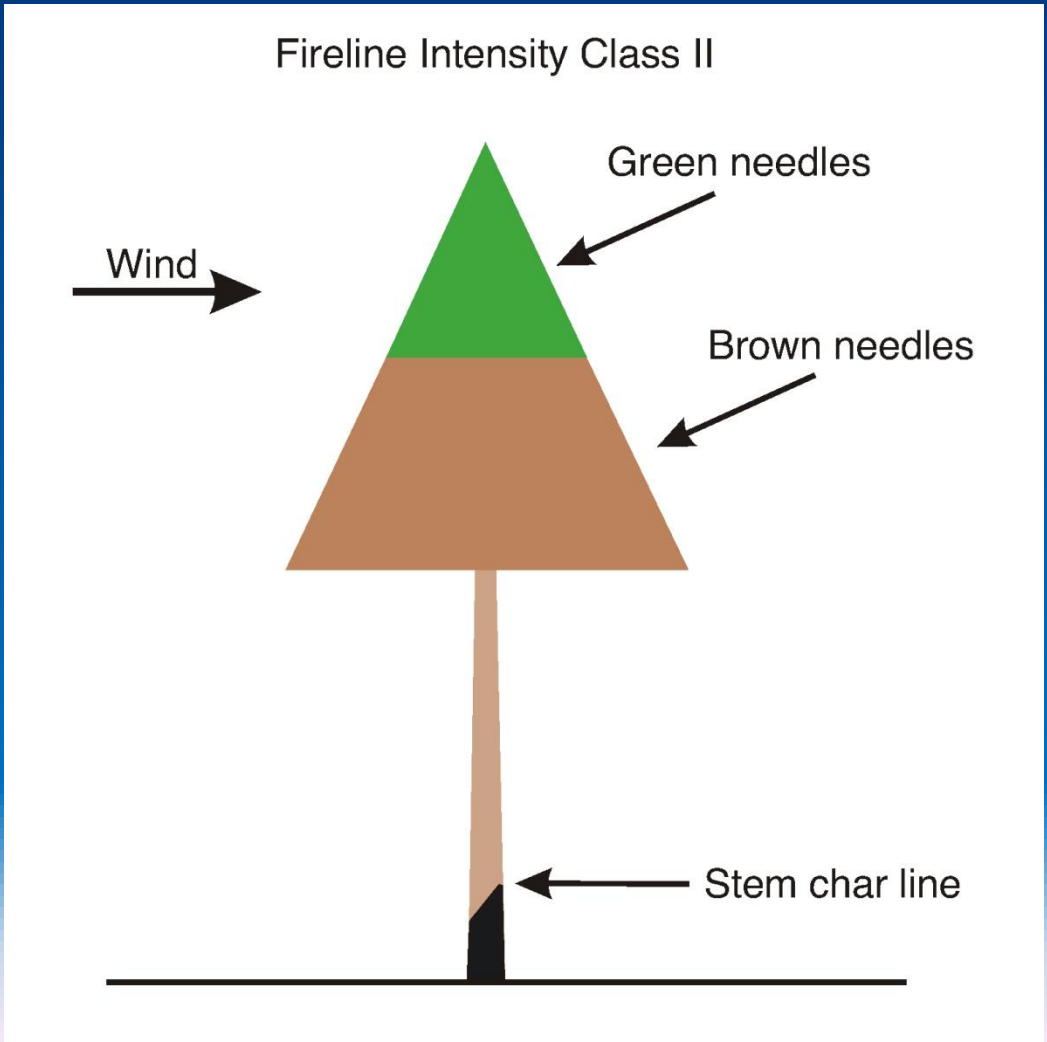


Fireline intensity level I: $h_s \leq CBH$
(no crown scorch or cone opening)

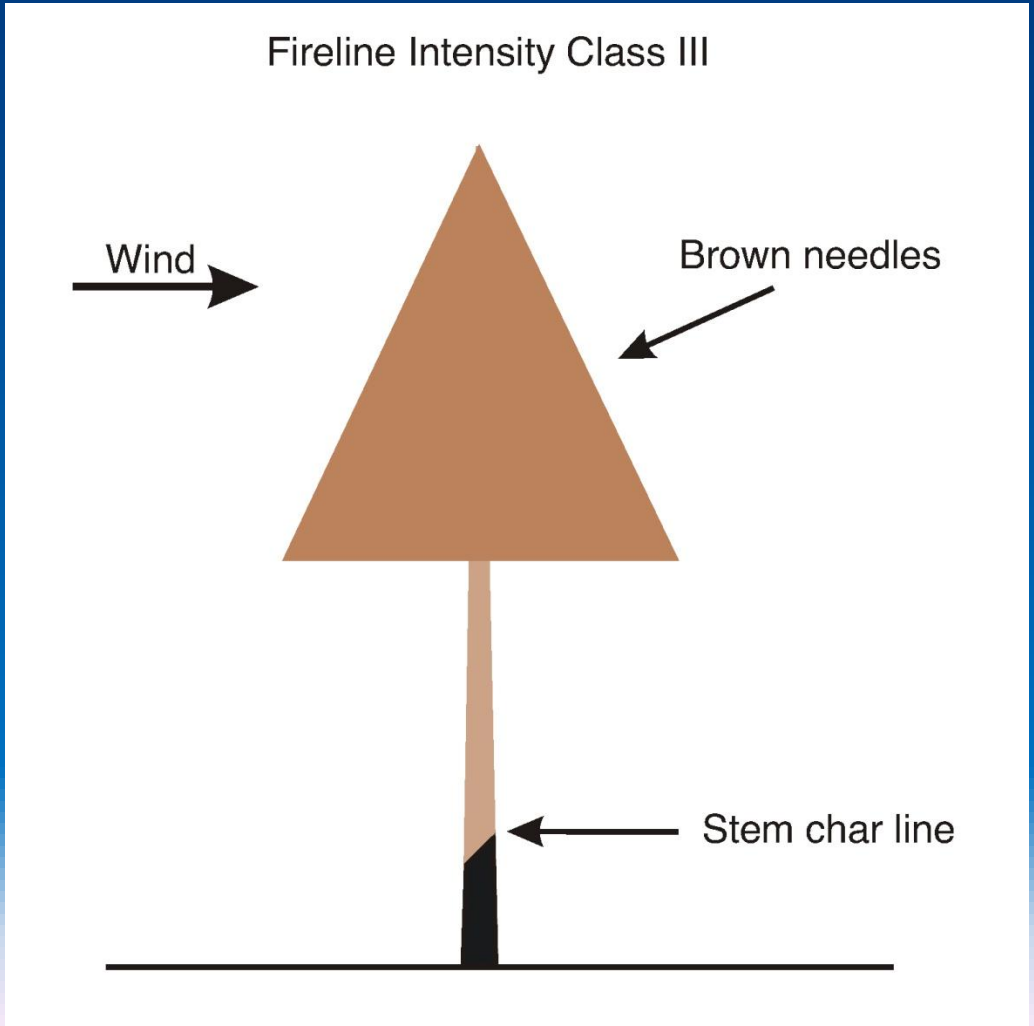


Fireline intensity level II: ***CBH*** $\leq h_s \leq$ ***SH***

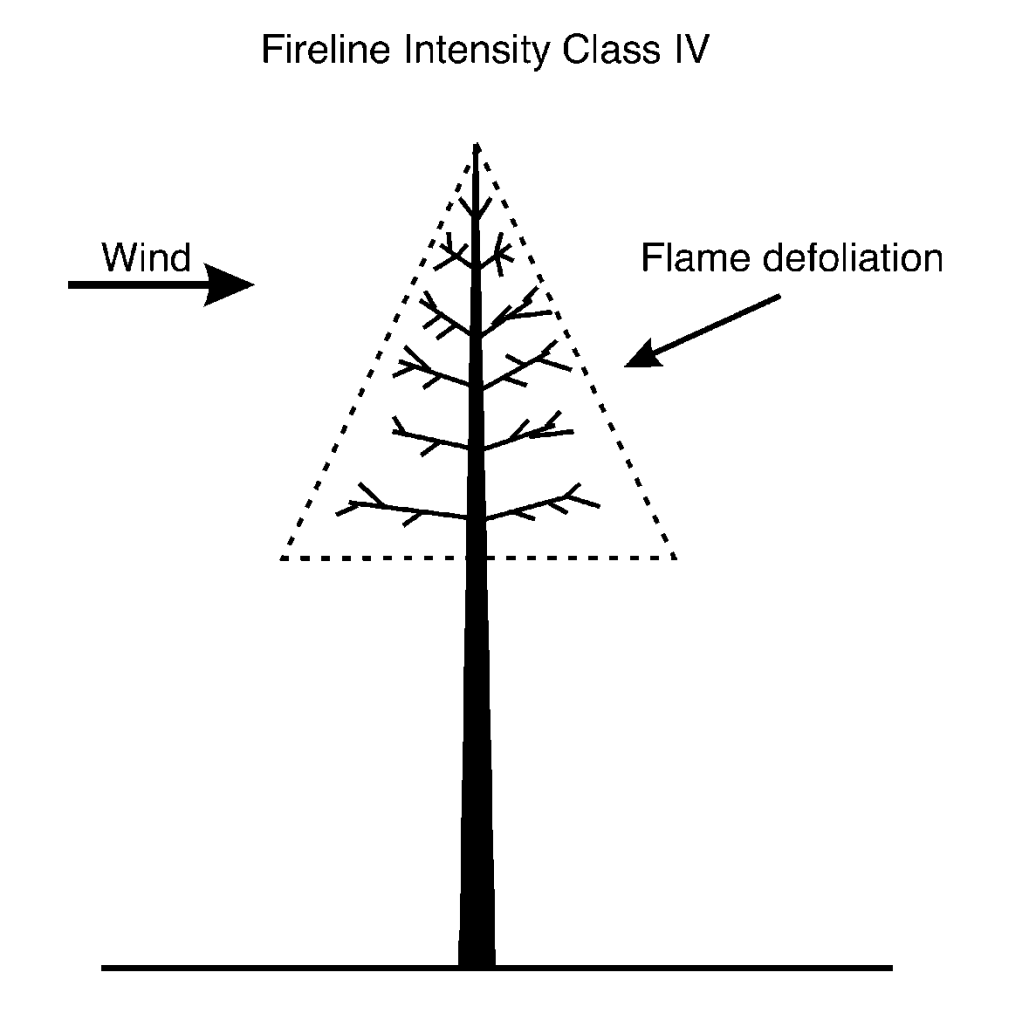
(partial to nearly complete crown scorch and no cone opening)



Fireline intensity level III: $h_s \geq SH$ and $I \leq I_o$
(full crown scorch and cone opening by convective and radiative heating)



Fireline intensity level IV: $I \geq I_o$ (crown fire; flame defoliation of the overstorey canopy, full cone opening as a result of direct flame contact, and cone charring)

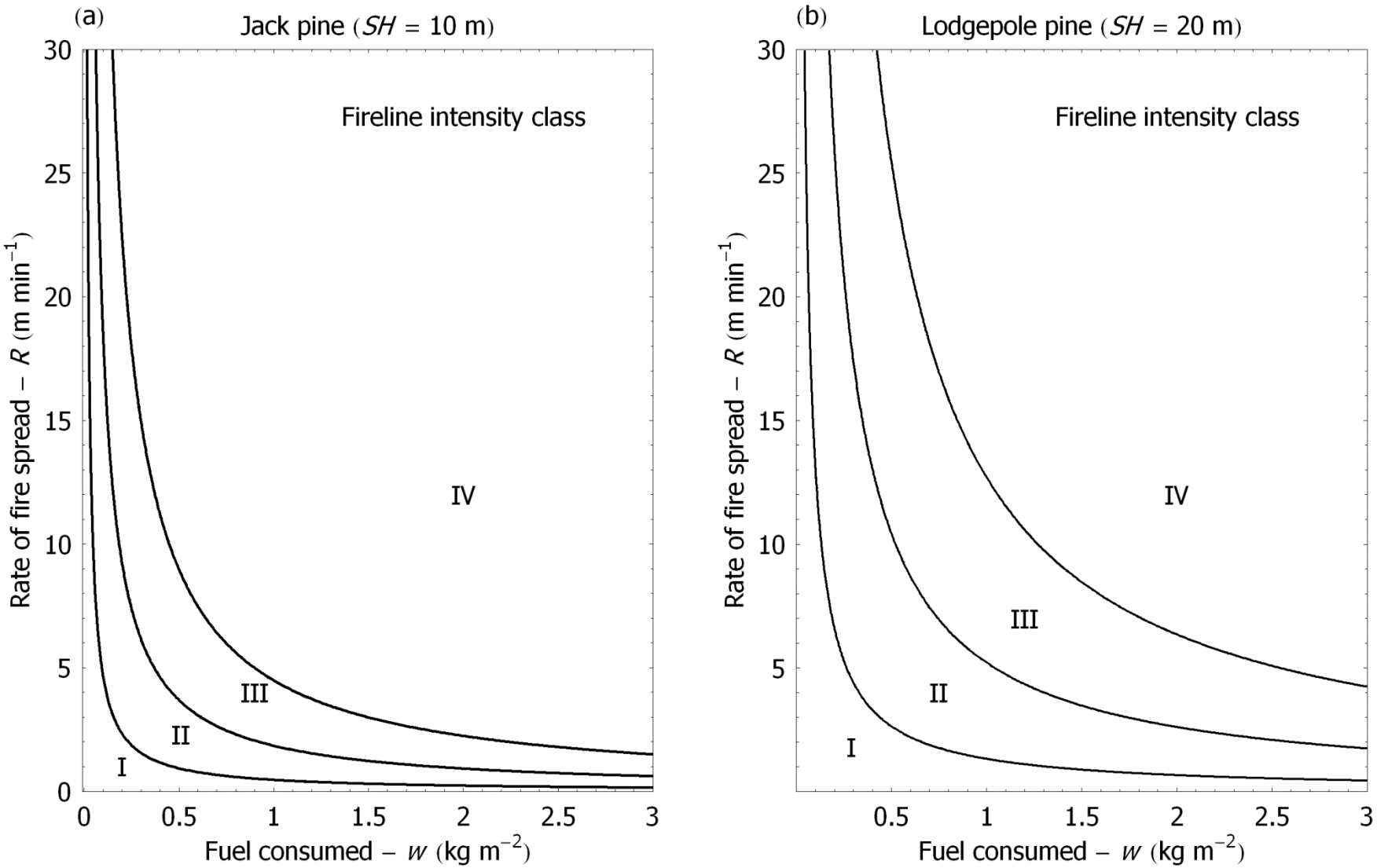


Two Contrasting Examples:

	Jack Pine	Lodgepole Pine
SH (m)	10	20
CBH (m)	4	8
FMC (%)	100	100
CBD (kg m^{-3})	0.2	0.1

Assumptions: (i) cones are distributed vertically throughout the live overstory canopy and (ii) t_r at the ground surface is 1.0 min.

Canopy Fire Impact Charts



Fireline intensity level	Type of fire and associated impact on cones and tree crowns	Jack pine (*SH* = 10 m, *CBH* = 4 m)	Lodgepole pine (*SH* = 20 m, *CBH* = 8 m)
		kW m^{-1}	kW m^{-1}
I	Low-intensity surface fire; no crown scorch or cone opening.	< 140	< 396
II	Moderate-intensity surface fire; partial to nearly complete crown scorch of the overstory canopy and no cone opening.	140-554	396-1566
III	High-intensity surface fire; full crown scorch of the overstory canopy and cone opening by convective and radiative heating.	554-1346	1566-3811
IV	Crown fire; flame defoliation of the overstory canopy, full cone opening as a result of direct flame contact, and cone charring.	≥ 1346[a]	≥ 3811[b]

[a] The transition between passive and active crowning occurs when *R* is ≥15 m min^{-1}.

[b] The transition between passive and active crowning occurs when *R* is ≥30 m min^{-1}.

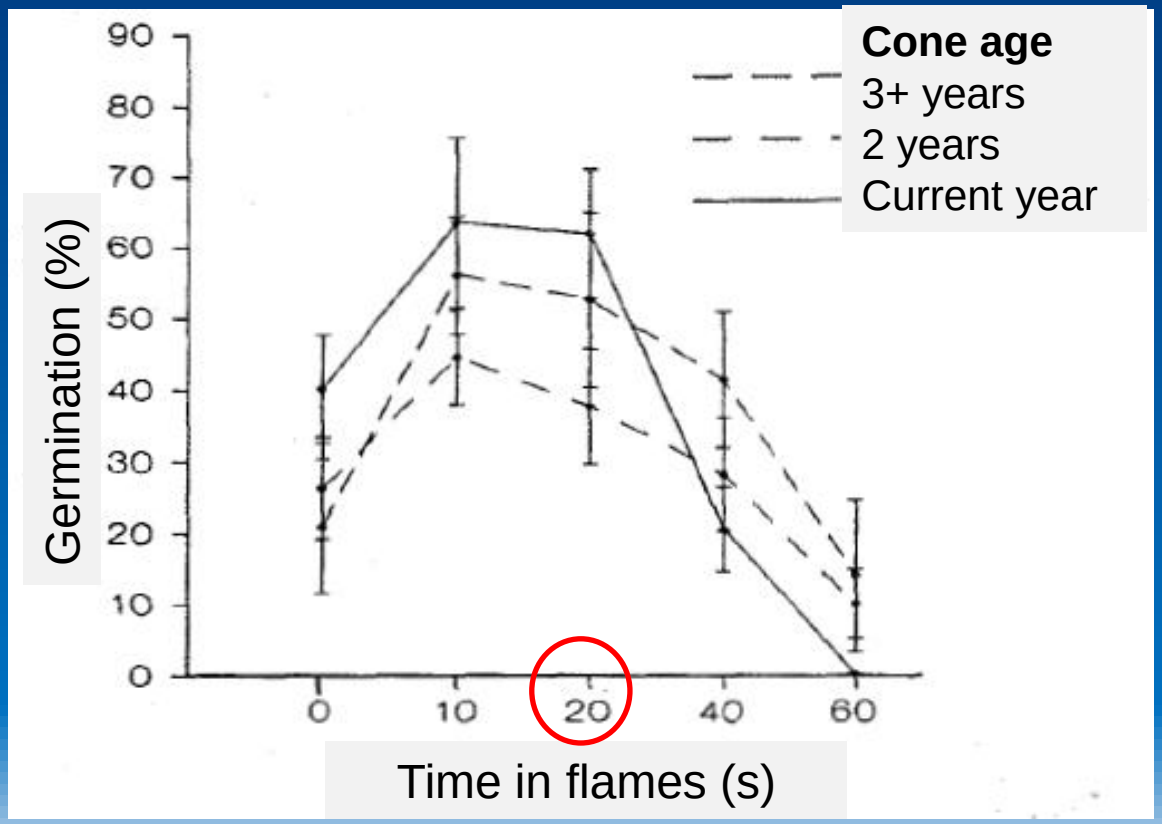
A general validation

Corroborated by a large body of empirical evidence of fire-induced tree regeneration in relation to quantified fire behavior on experimental fires (e.g., Weber *et al.* 1987; Stocks *et al.* 2004) and wildfires (e.g., Ohmann & Grigal 1979).

Despain *et al.* (1996) analyzed segments of video footage taken of the 1988 Yellowstone fires.

Duration of flaming average 24.5 seconds (SD ±9.6) and ranged from 5 to 48 seconds with no significant difference between single trees and stands of trees.

Seed mortality in relation to flame residence times in crown fires



Despain *et al.* (1996)

Conclusions

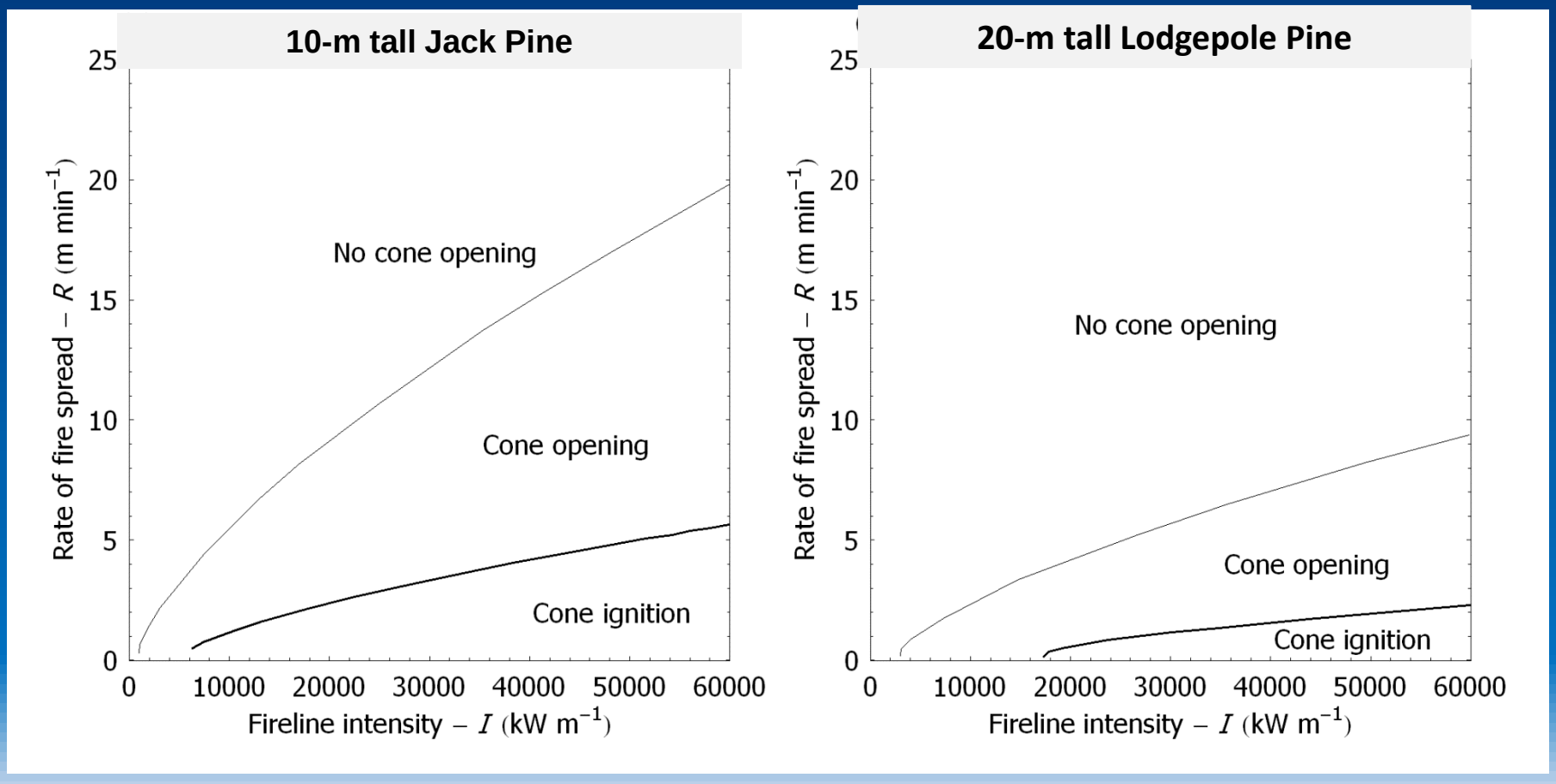
- The breaking of the resinous bond that holds the cone scales together is dictated by the type of fire.
- In surface fires this occurs as a result of convective and radiative heating begins to occur once full crown scorch attained and prior to crown fire initiation. Cone opening by direct flame contact occurs with the onset of crowning.
- Seed mortality is expected to occur in active crown fires once flame front residence times at the ground surface exceed 50 seconds.

Closing Remarks

The work reported here is a result of coupling years of field observation with advances in the science of wildland fire behavior to the fire ecology literature of the two pine species.

The results are an approximation or simplification of the real world as we know them, based on existing knowledge.

Johnson & Gutsell (1993) modelled outcomes



R **= 1.0 m min^{-1} and *I* = 60 000 kW m^{-1}, then *w* = 200 kg m^{-2}**

Alexander, M.E.; Cruz, M.G. 2012. **Modelling the impacts of surface and crown fire behaviour on serotinous cone opening in jack pine and lodgepole pine forests.** *International Journal of Wildland Fire* 21: 709-721.

Thank you for your attention!

QUESTIONS? COMMENTS?

If not … HAPPY HALLOWEEN !!!