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

Marty Alexander
University of Alberta

Interior West Fire Ecology Conference:
Challenges and Opportunities in a Changing World
Snowbird Resort, Utah, November 14-17, 2011

Serortinous cones of jack pine and lodgepole pine:

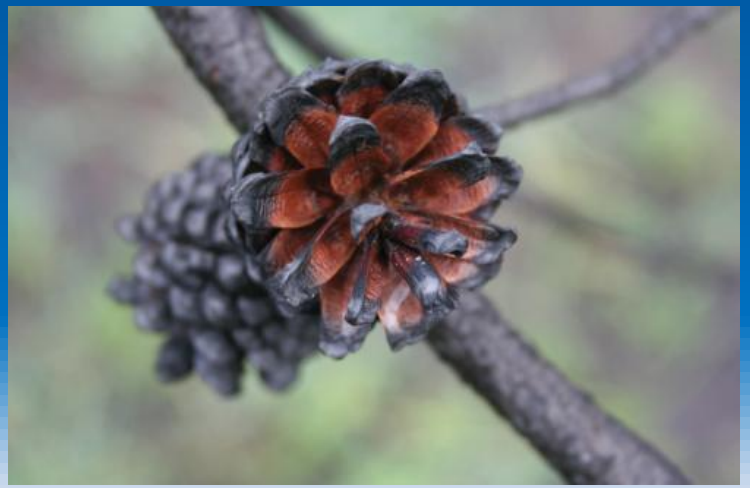
sealed shut by a resinous bond at the tips of the cone scales require high temperatures for them to open

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.



Basic descriptor of a spreading heat source:

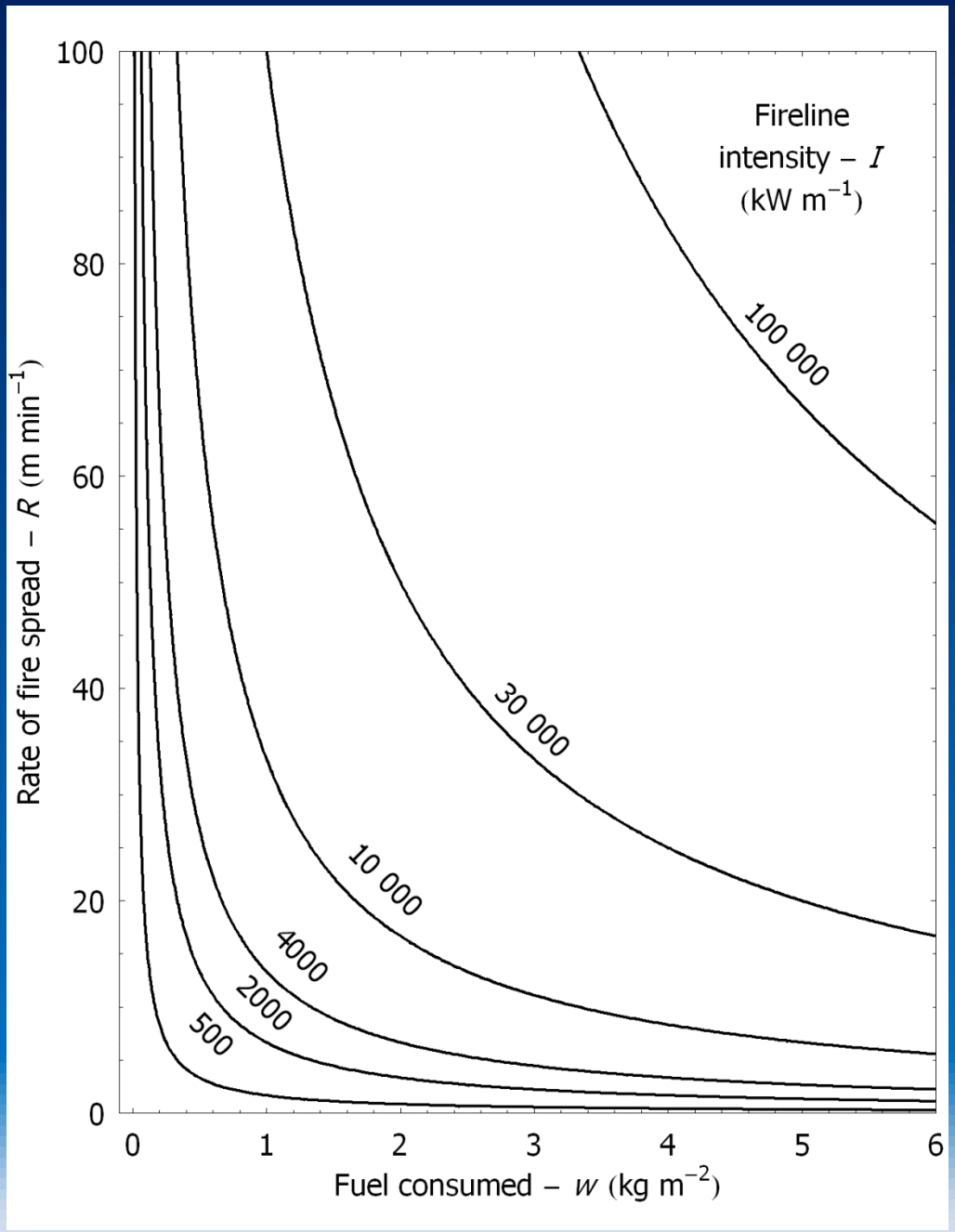
$$I = H \cdot w \cdot r$$

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}

1 Btu/sec-ft = approx. 3.5 kW/m

Convective heating of the overstory canopy by surface fire:

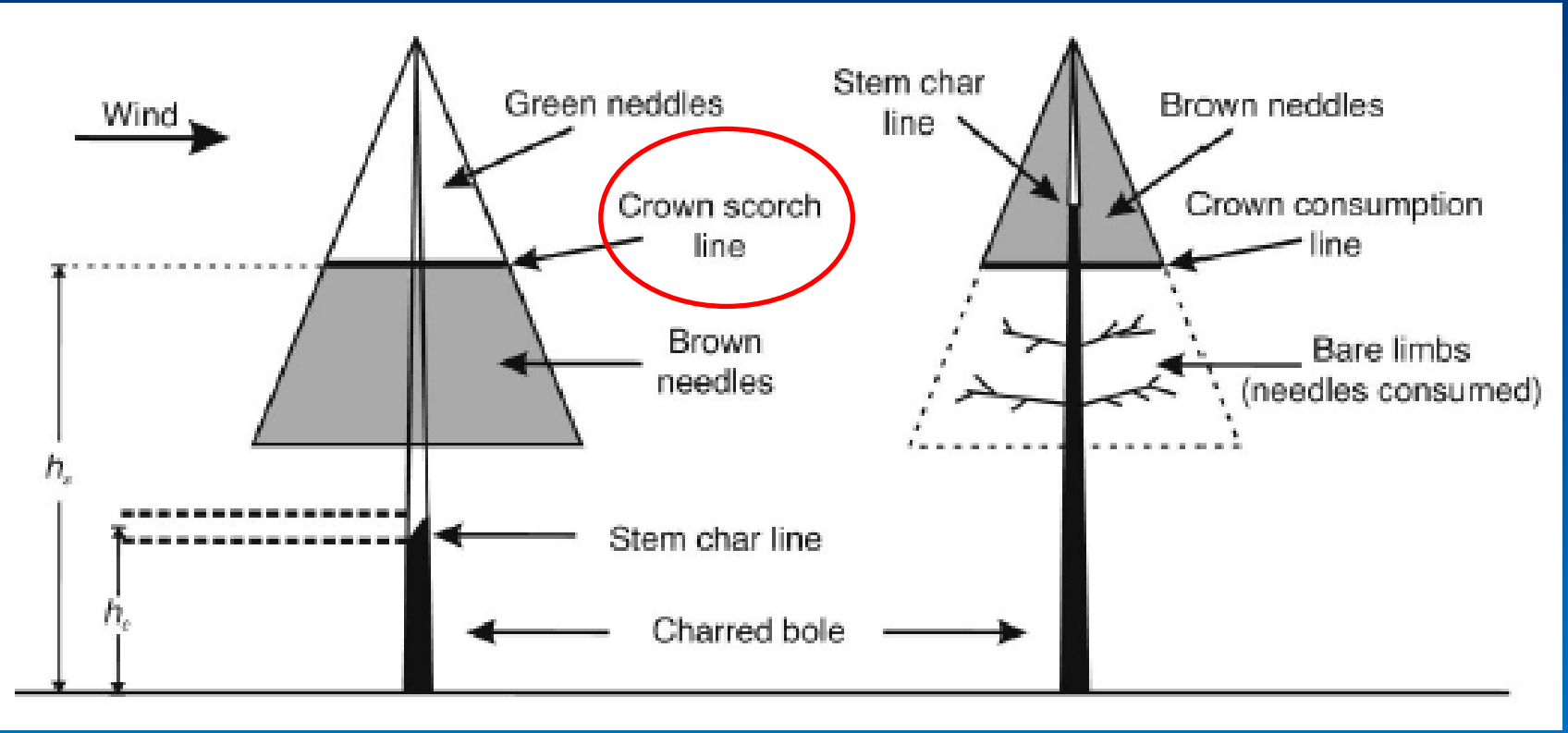
$$\Delta T = \frac{3.85 \cdot I^{2/3}}{z}$$

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

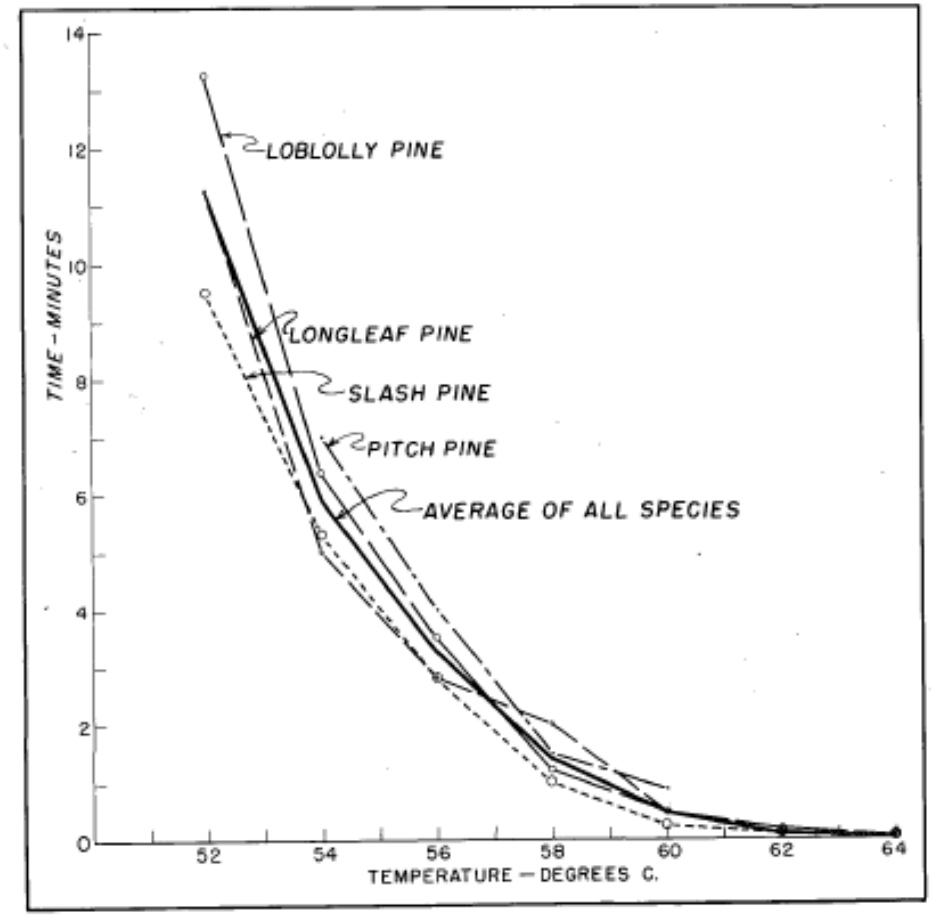
I – Byram's (1959) fireline intensity (kW m^{-1})

z – Height above ground (m)

Crown scorch height



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

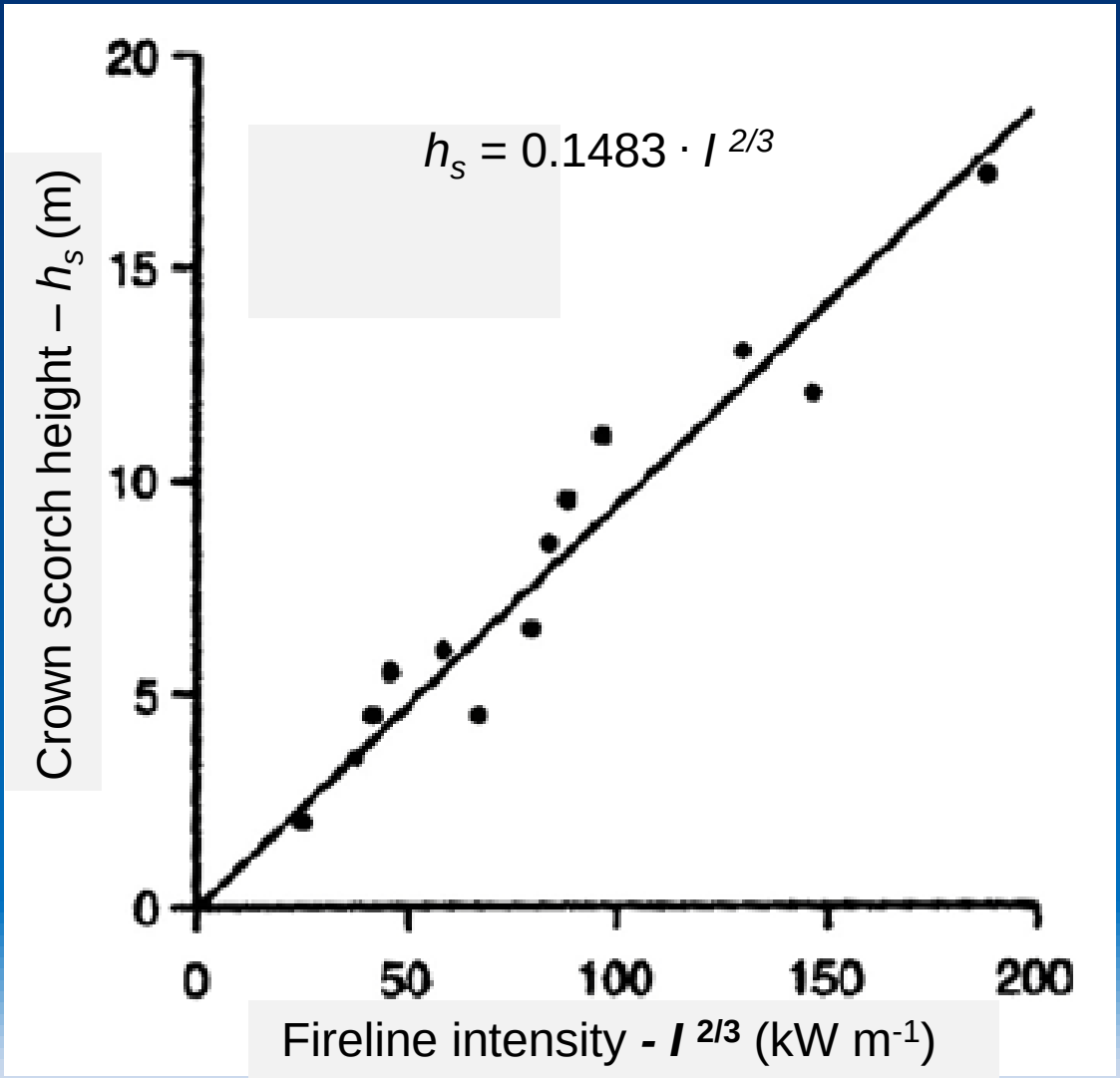


Killing temperatures for southern pine needles when immersed in a water bath.

Byram & Nelson (1952)

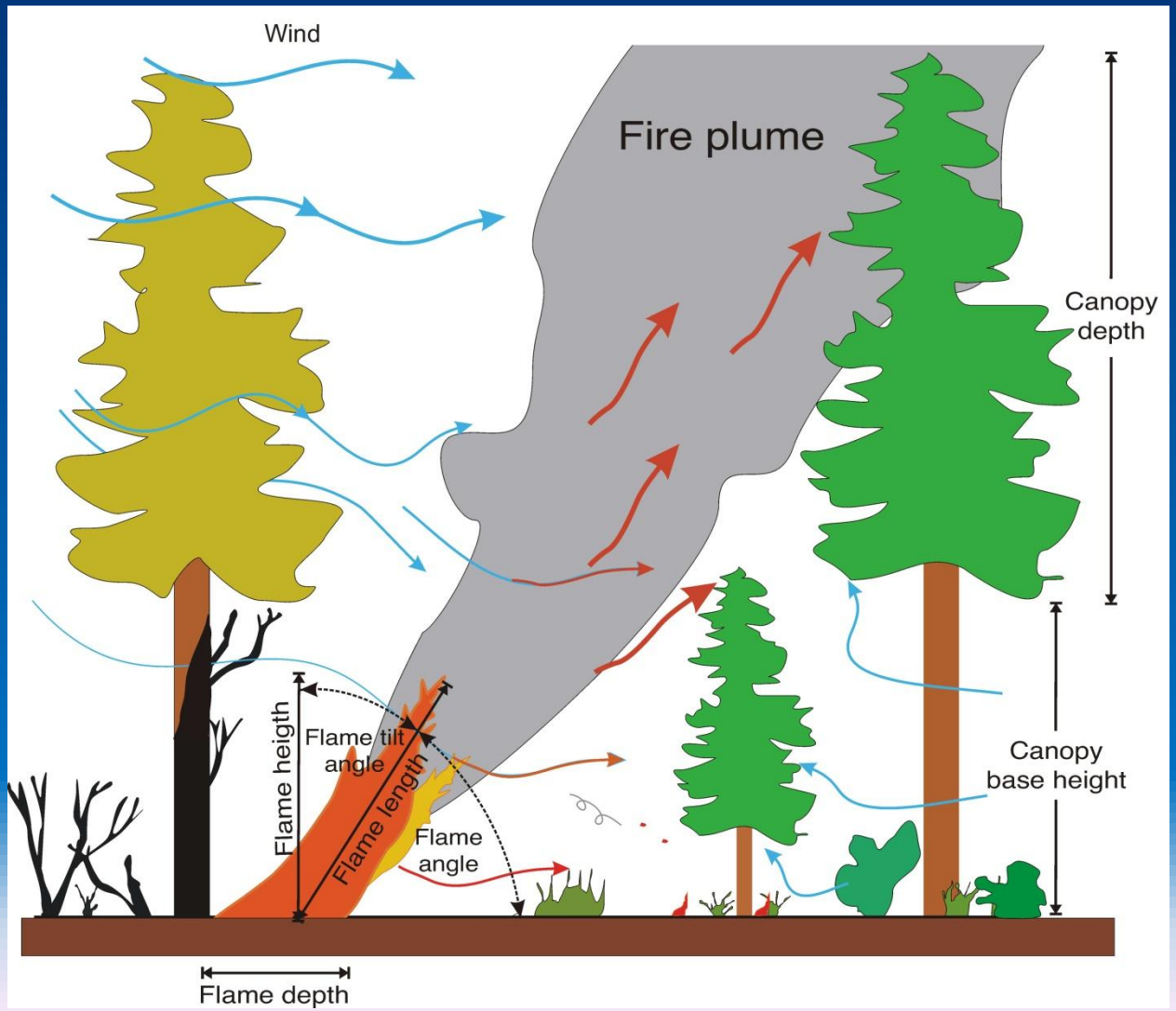
Van Wagner (1973)
crown scorch height – fireline intensity model

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.

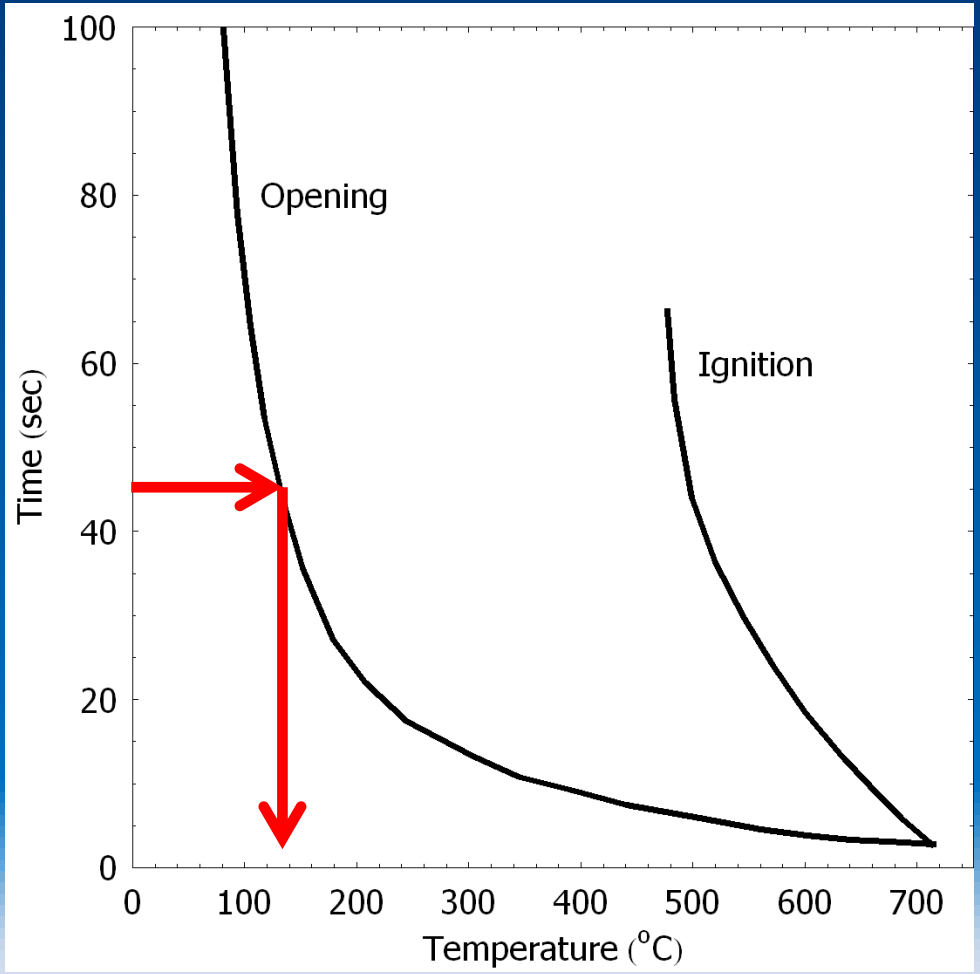
Numerically, the flame front residence time (t_r , min) equal to the horizontal flame depth (***D***, m) of a spreading fire divided by the fire's rate of advance (***R***, m min^{-1}):

$$t_r = D \div R$$

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 ^{o}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})

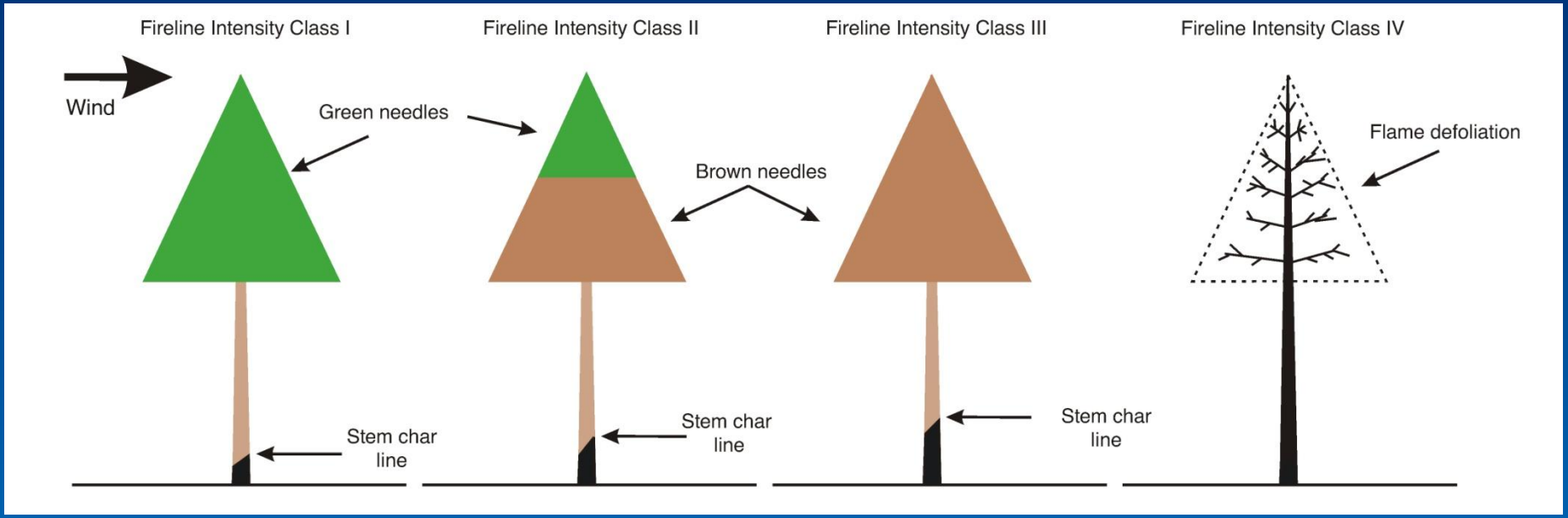
CBD – Canopy bulk density (kg m^{-3})
(*CBD* = canopy fuel load ÷ live crown length)

Canopy Flame Front Residence Times

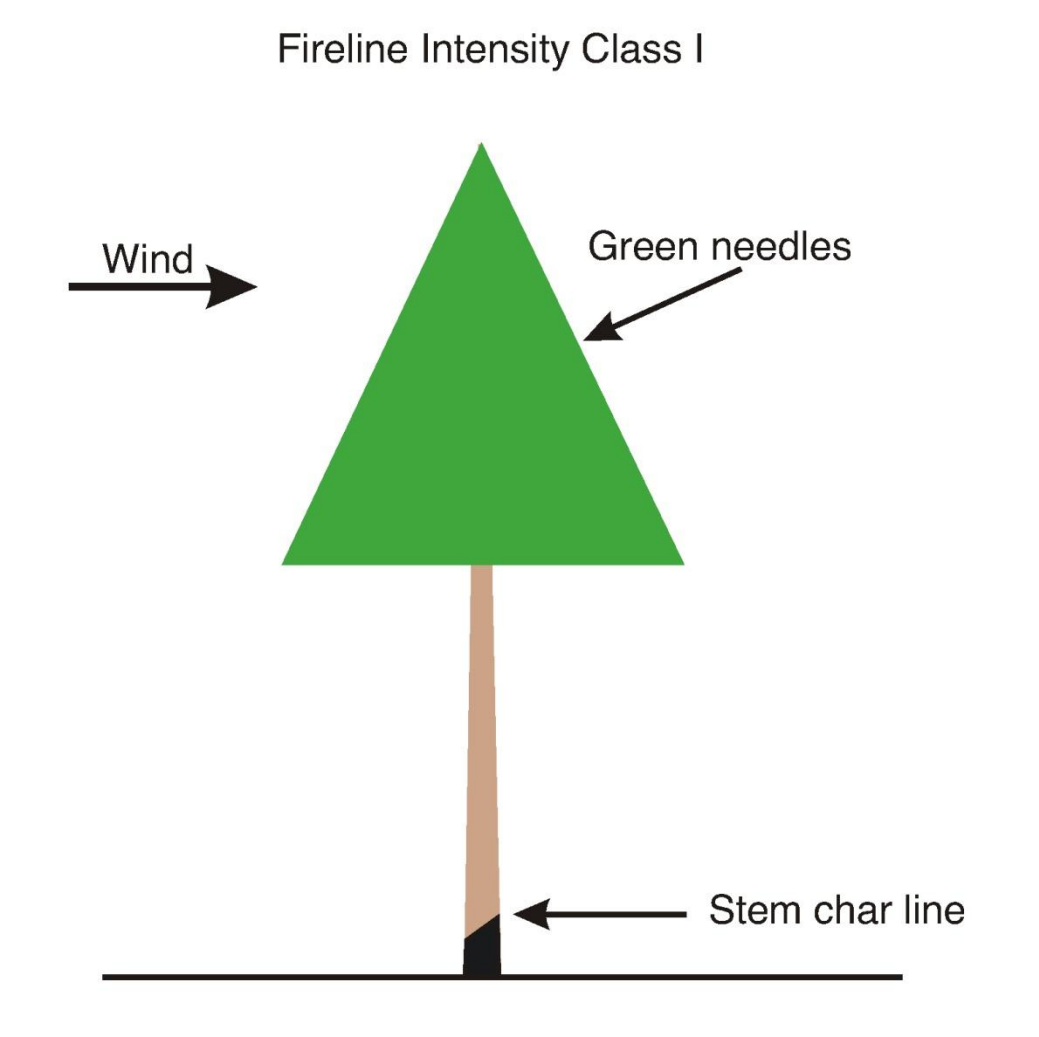
t_r at the ground surface vs. t_r in the live canopy
~ 2.5: 1 ratio

Post-burn mosaic of canopy fire impact types

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

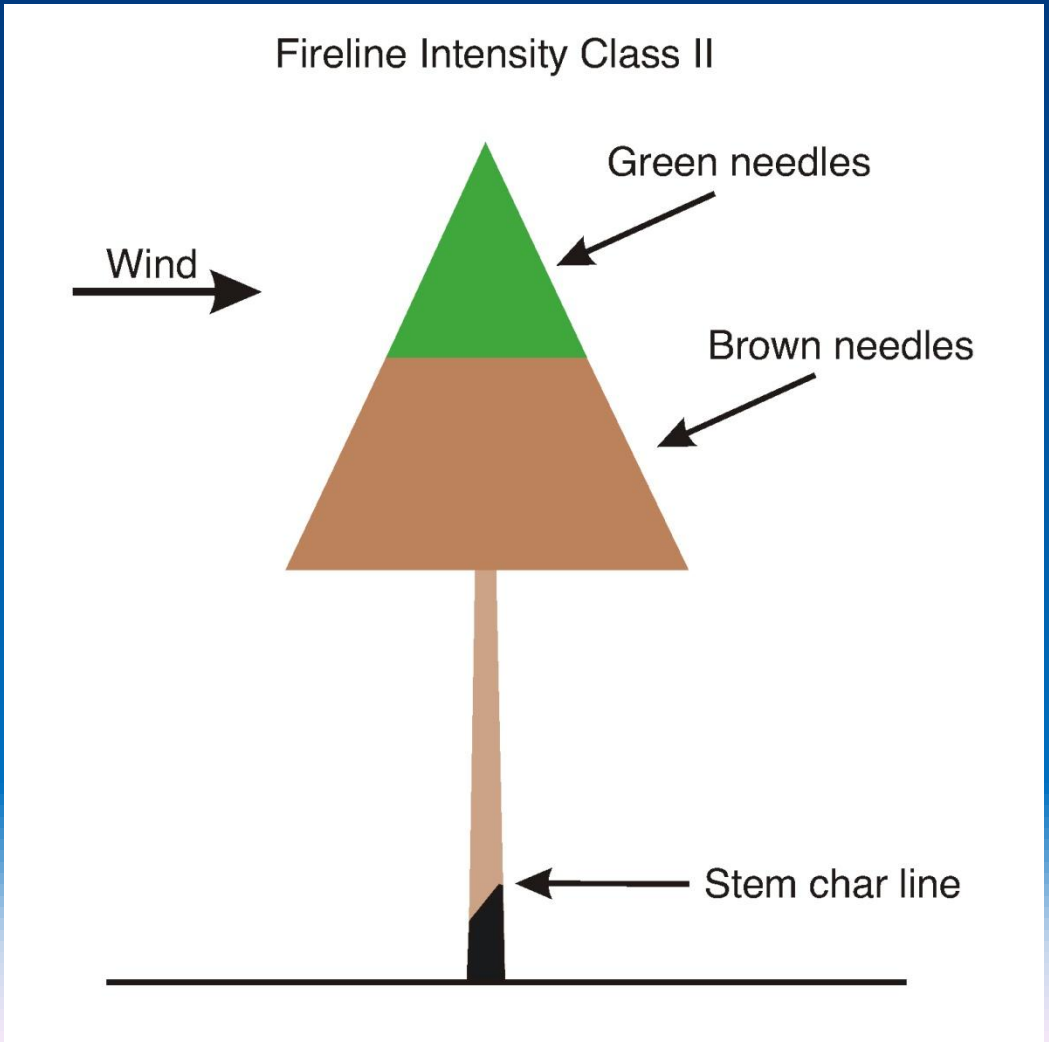


Fireline intensity level I: $h_s \leq CBH$
(no crown scorch or cone opening)

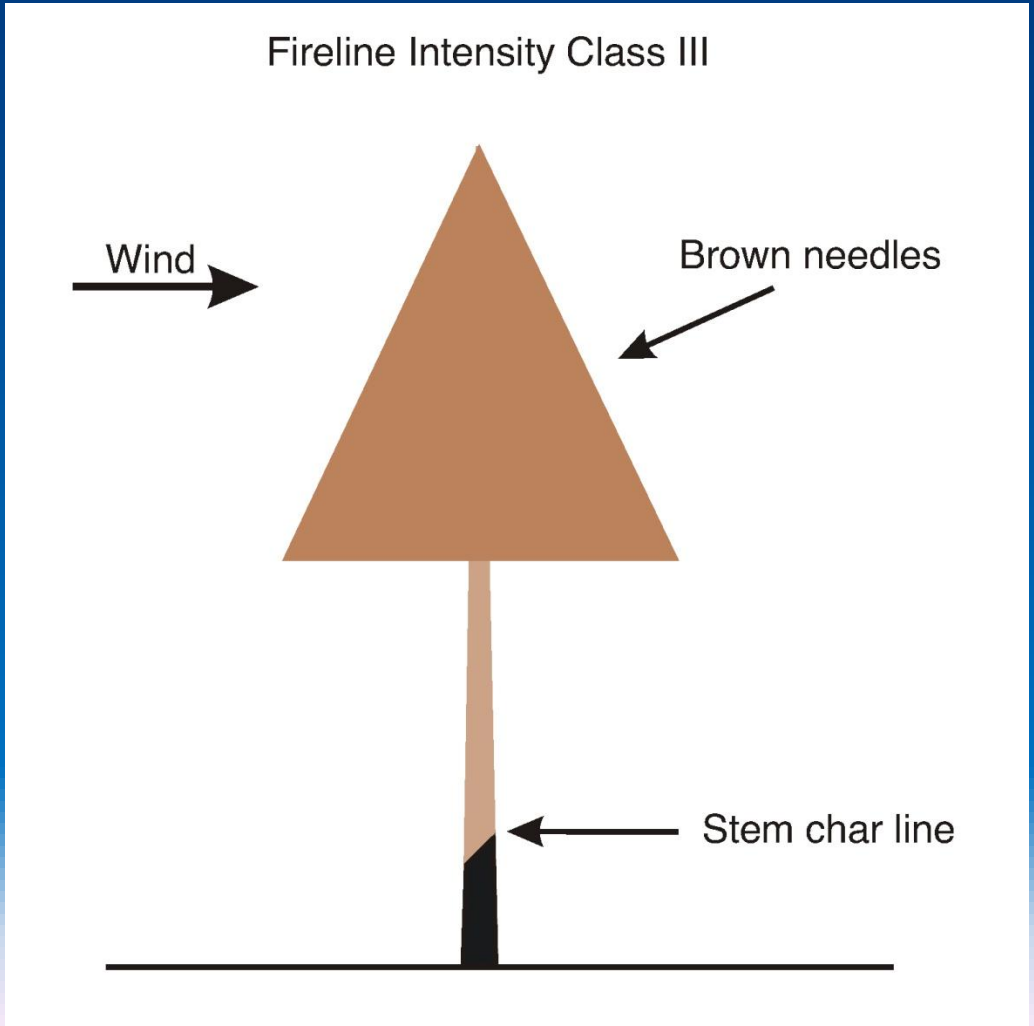


Fireline intensity level II: ***CBH*** $\leq h_s \leq$ ***SH***

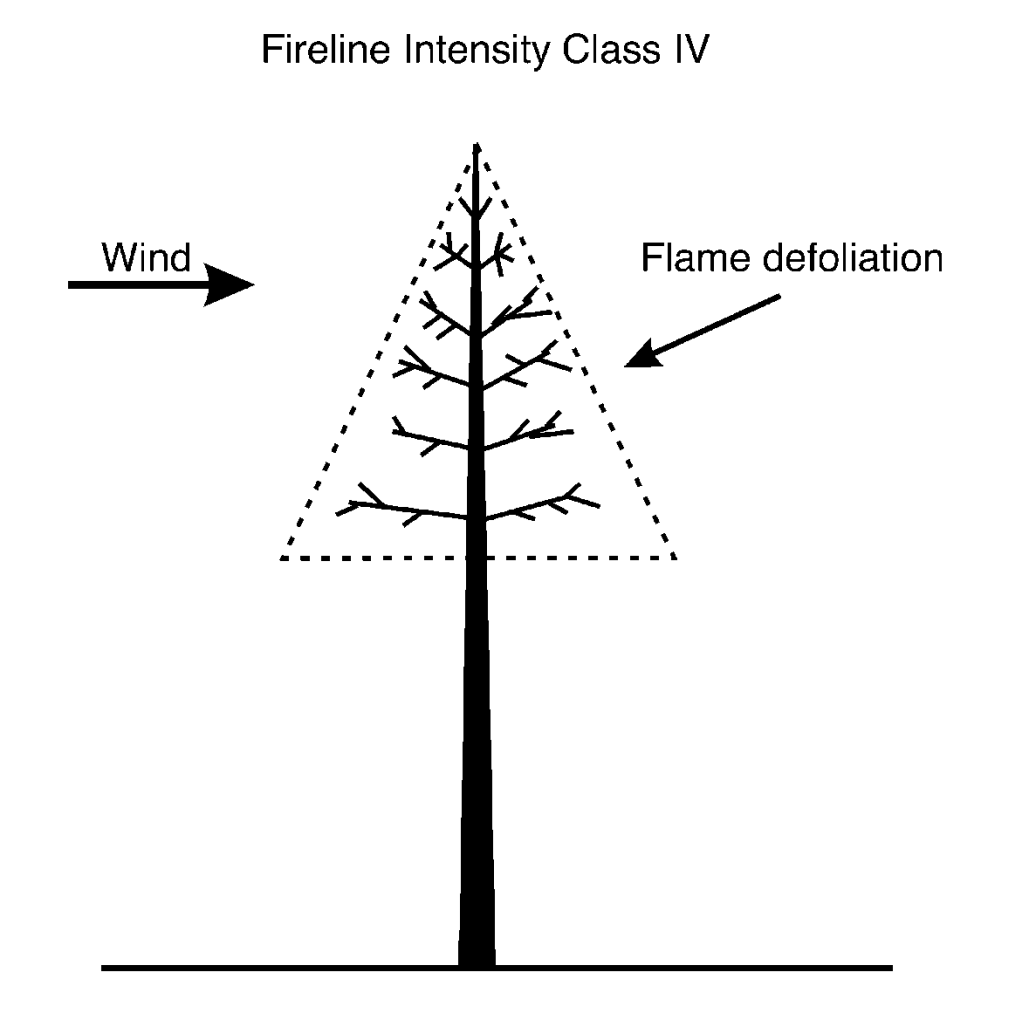
(partial to nearly complete crown scorch and no cone opening)



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)

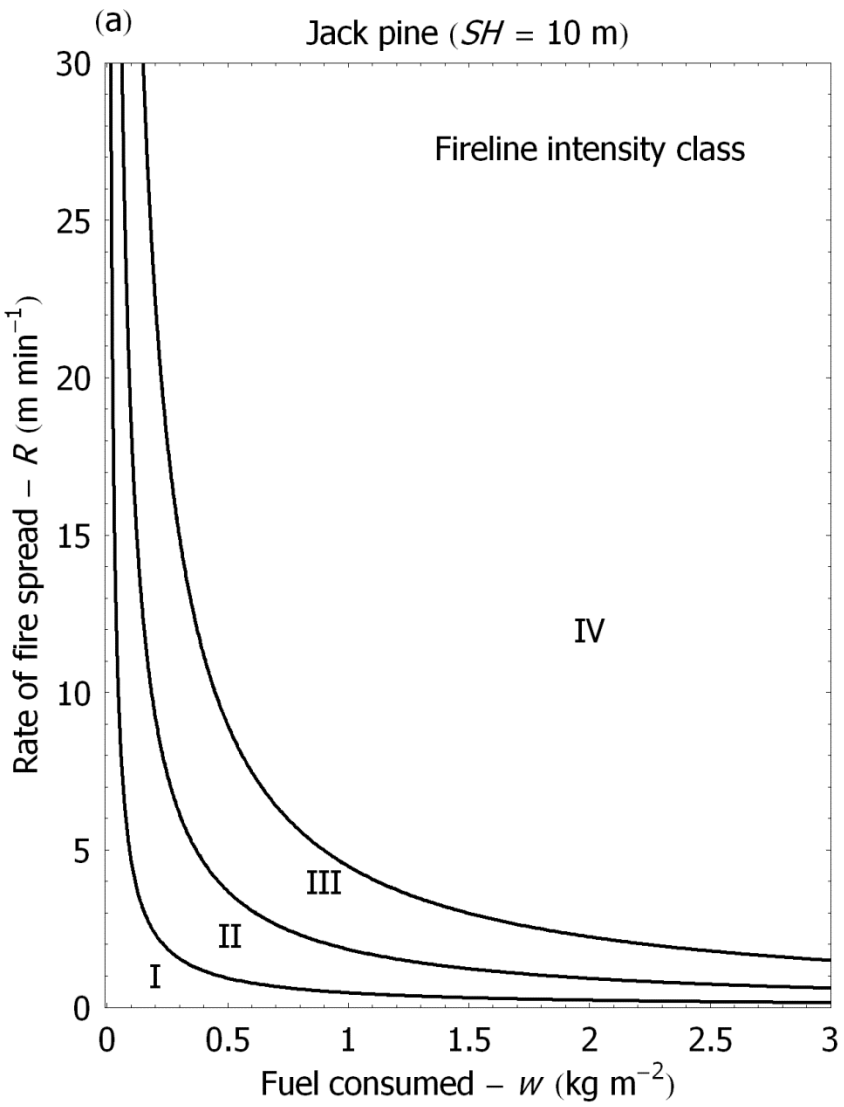


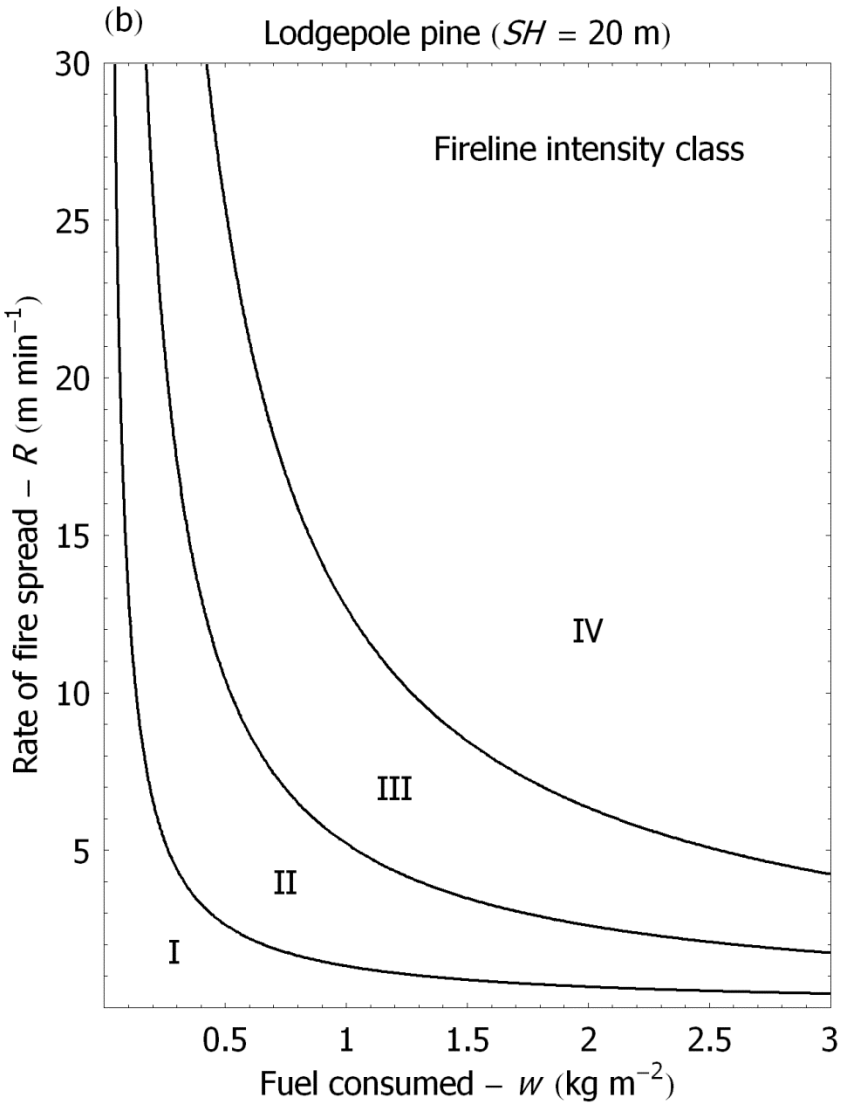
Two Contrasting Examples:

	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]

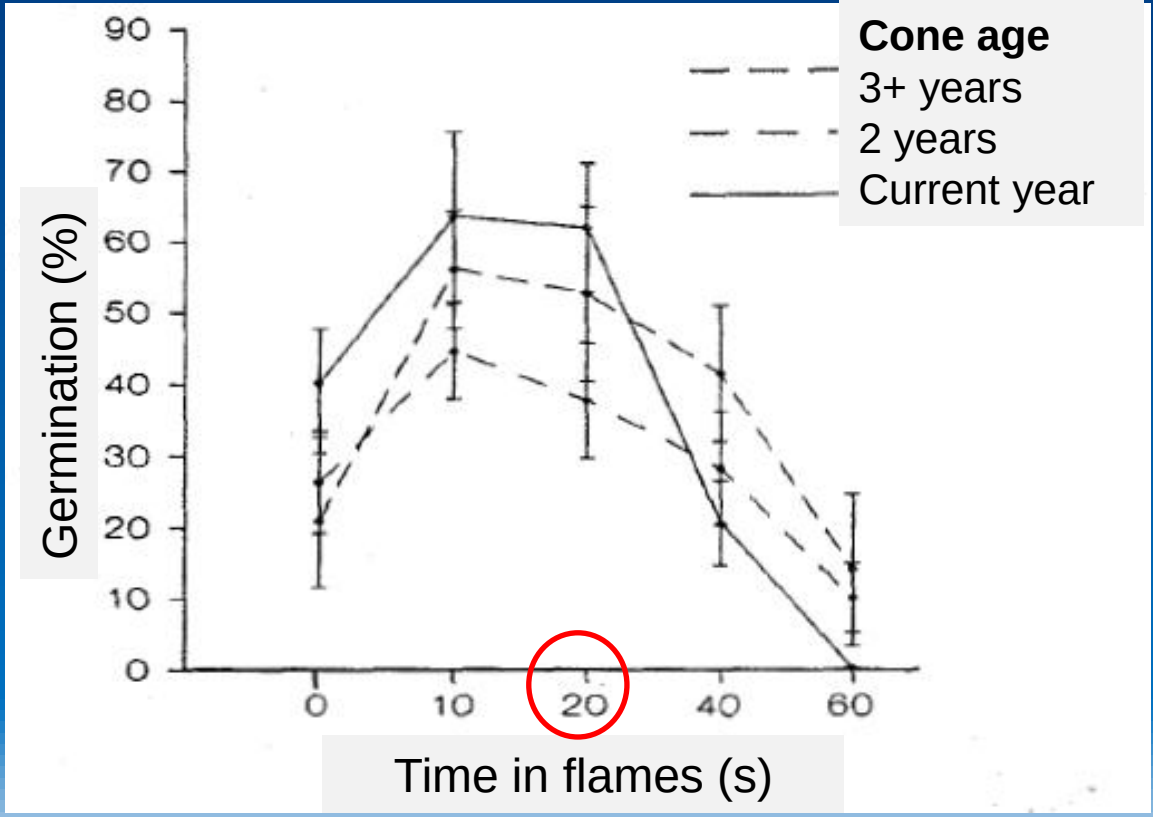
[a] The transition between passive and active crowning occurs when *R* is ≥15 m min^{-1}.

[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).

Seed mortality in relation to flame residence times in crown fires



Despain *et al.* (1996)

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.

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.

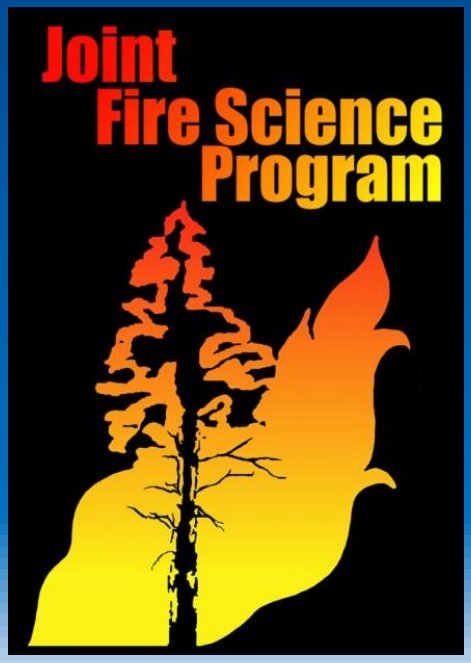
Closing Remarks

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.

Acknowledgement

This is a contribution of Joint Fire Science Program Project JFSP 09-S-03-1



Crown fire behavior characteristics and prediction in conifer forests: A state of knowledge synthesis

http://www.fs.fed.us/wwetac/projects/alexander.html

mea2@telus.net