Mapping fire pathways for mitigation and contingency planning

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Wildfires can impact communities

- **547** evacuation events
- **497** homes destroyed
- **209,121** evacuees
- Median number evacuated per year: 3,590
- Median number of homes lost: 2
- Median distance from fire: 3 km
- Prompted by smoke: 19%
- Civilian fatalities: 1

More people evacuated 2011-2018 than in the previous 31 years
Trend or outliers?

<table>
<thead>
<tr>
<th>Location</th>
<th>Date</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kelowna 2003</td>
<td>August 2003</td>
<td>70 km/h winds, 27,000 evacuated, 239 homes destroyed, $200M in damages</td>
</tr>
<tr>
<td>Slave Lake 2011</td>
<td>May 2011</td>
<td>100 km/h winds, 7,000 evacuated, 433 homes destroyed, $700M insured damages</td>
</tr>
<tr>
<td>Fort McMurray 2016</td>
<td>May 2016</td>
<td>72 km/h winds, 90,000 evacuated, 2,400 homes destroyed, $3.6B insured damages</td>
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<tr>
<td>Lytton 2021</td>
<td>June 2021</td>
<td>70 km/h winds, 1,000 evacuated, Village 90% destroyed, $78M insured damages</td>
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</tbody>
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(Photo sources: Andy Clark/Reuters; Town of Slave Lake; Twitter.com/Jerome Garot/EPA; Edith Loring-Kuhanga/Facebook)
Fire Weather Index (FWI)
A numeric rating of fire intensity.
Used as general index of fire danger throughout the forested areas of Canada.

A numeric rating of fire intensity, used as a general index of fire danger throughout the forested areas of Canada.
“the perfect storm” – when a confluence of many factors or events – no one of which alone is particularly devastating – creates a catastrophic force. Such confluence is rare and devastating (Emanuel and Fuchs 2008).
“grey swan” – known events with unknown likelihood (Nafday 2011); we can specify outcomes but not probabilities (Gholami et al. 2018); we are in a state of “incomplete” knowledge in which attempts to assign probabilities are neither rational nor science-based (Sterling 2007).
Fuel characteristics (structure) matters

Fuels are the hazard (potential source of harm)

Amount of surface fuel

Amount and compactness of crown fuel

Crown base height
Fire intensity dictates suppression effectiveness

\[ I = h \cdot w \cdot r \]

- **Ground**
- **Surface**
- **Crown**

**Suppression success**
- < 10 kW/m
- 2,000 – 4,000 kW/m

**Suppression failures**
- 10 – 500 kW/m
- 500 – 2,000 kW/m
- 4000 – 10,000 kW/m
- > 10,000 kW/m

Threshold for ground crew effectiveness
Threshold for airtanker effectiveness
Where can we expect fires? Fixed versus variable factors

There are things we can know for today, the next several days

- Fuel moisture (availability)
- Wind speed, direction
- Ignition agents

Highly variable within a fire season (lots of predictive uncertainty)

There are things we can know for this season, the next several seasons

- What burns, where it is (fuel)
- Operational capabilities
- Location of values (receptors)

Mostly fixed within a fire season (lots of certainty)
Threat rating

- Number of fires per 4 km² 1950-1991
- Rate of spread; intensity; crown fraction burned
  - Initial attack time; terrain; water proximity
- Development; timber values; visual quality

Wildfire Threat

Wildfire threat map and four component maps of the Wildfire Threat Rating System for McGregor Model Forest

Spatial context – fires are contagious

- Point estimate of a threat is detached from the spatial context of its surrounding fuel neighbourhood
- Ignores the contagious nature of fires

Photo source: https://peakvisor.com/park/elk-island-national-park.html
Solution? Simulate the spread of fires

\[ I = h \cdot w \cdot r \]

- Rate of spread (\( n = 48 \))
- Weight of fuel consumed (\( n = 13 \))
- Constant – heat of combustion

C-2 Boreal Spruce

Image source: N. McLoughlin
Many simulations - express fixed and variable factors

Monte Carlo simulation process

Iteration 1
Many simulations - express fixed and variable factors

Monte Carlo simulation process

Iteration 2
Burn probability (BP) at a given pixel in the landscape grid is calculated as:

\[
\text{BP} = \frac{\text{# times the pixel burned}}{\text{# chances to burn (iterations)}}
\]
Stochasticity means thousands of iterations required

- Replicate maps can differ from each other
- To explore impacts of scenarios, modelers therefore fixed the fire sets by holding ignition points constant and then varying other inputs like the fuels or the weather

Base Case Replicate 1

Base Case Replicate 2

30% different
Does it work?

- 2.4 million ha study area
- 25,000 iterations
- 125,000 simulated fires
- Estimated with 2005 data
- Published 2009
- Slave lake burned 2011

Beverly et al. (2009)
Where did real fires burn?
Do fires burn preferentially in BP hotspots? No.

5 study areas
138 fires
543,049 ha burned

70% of burned areas occurred in areas where burn probability was in the lower half of the range (i.e., in the BP cold spots)
Exposure based on transmission distances

**Radiant Heat**

- **30 m**
- **100 m**
- **500 m**

**Longer range embers**

Beverly et al. (2009)

Simple metric of exposure (Beverly, McLoughlin, Chapman 2021)

There are 80 pixels within 500 m – how many can transmit fire to me?

\[
\text{exposure} = \frac{\text{hazard fuel pixels}}{\text{total pixels}} = \frac{75}{80} = 0.94
\]

94% exposure
Exposure based on 2007 fuel map

Overlaid fires in the years that followed (2007-2019)

2,331 fires, burned 2,606,387 ha

**Landscape fire exposure** – a numeric rating of the potential for fire transmission to a location given surrounding fuel composition and configuration, irrespective of weather or other fire controls.
What about weighting for distance, CFL, HFI, ROS?

- Tried weighting pixels by:
  - Nearness
  - Crown fuel load (CFL)
  - Head fire intensity (HFI)
  - Rate of spread (ROS)

Tried increasing window to 1000 m

Increased complexity did not improve correspondence with real fires
Can be combined with variable fire controls

**Landscape fire exposure** — a numeric rating of the potential for fire transmission to a location given surrounding fuel composition and configuration, irrespective of weather or other fire controls.
Using exposure configuration to define fire pathways
We know most burned area happens where exposure is ≥ 60%
Focus on those critical exposure areas
Assess configuration of exposure in different directions
Validate approach with real fires
Most transects overlap with critical exposure

Proportion of transect with overlap

Percent of sample transects
Plot the directional configuration of critical exposure areas
Simplify to visualize pathways
Jasper fire pathways

Photo source: https://cwfs.cfs.nrcan.gc.ca/interactive-map
Thank you, looking forward to questions and discussion

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