Canada Wildfire / NSERC Strategic Network

James Lab Update

<u>The role of insect outbreaks on wildfire activity</u>

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Kennedy Korkola, Doriana Romualdi

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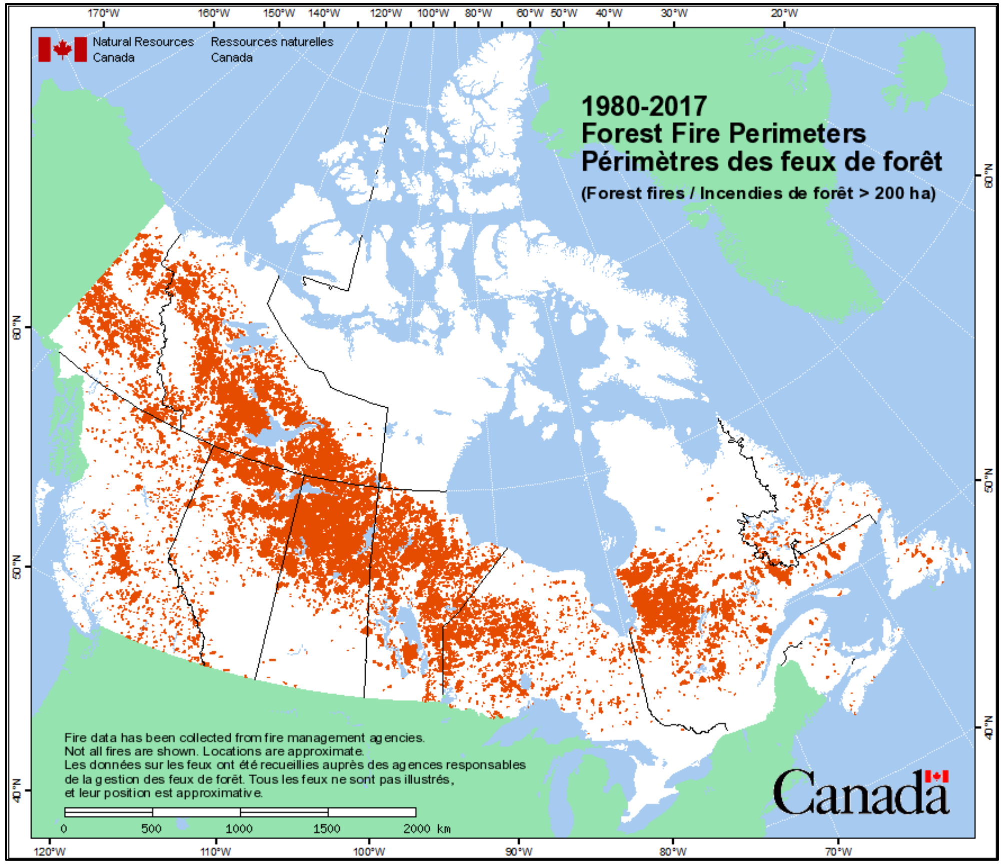
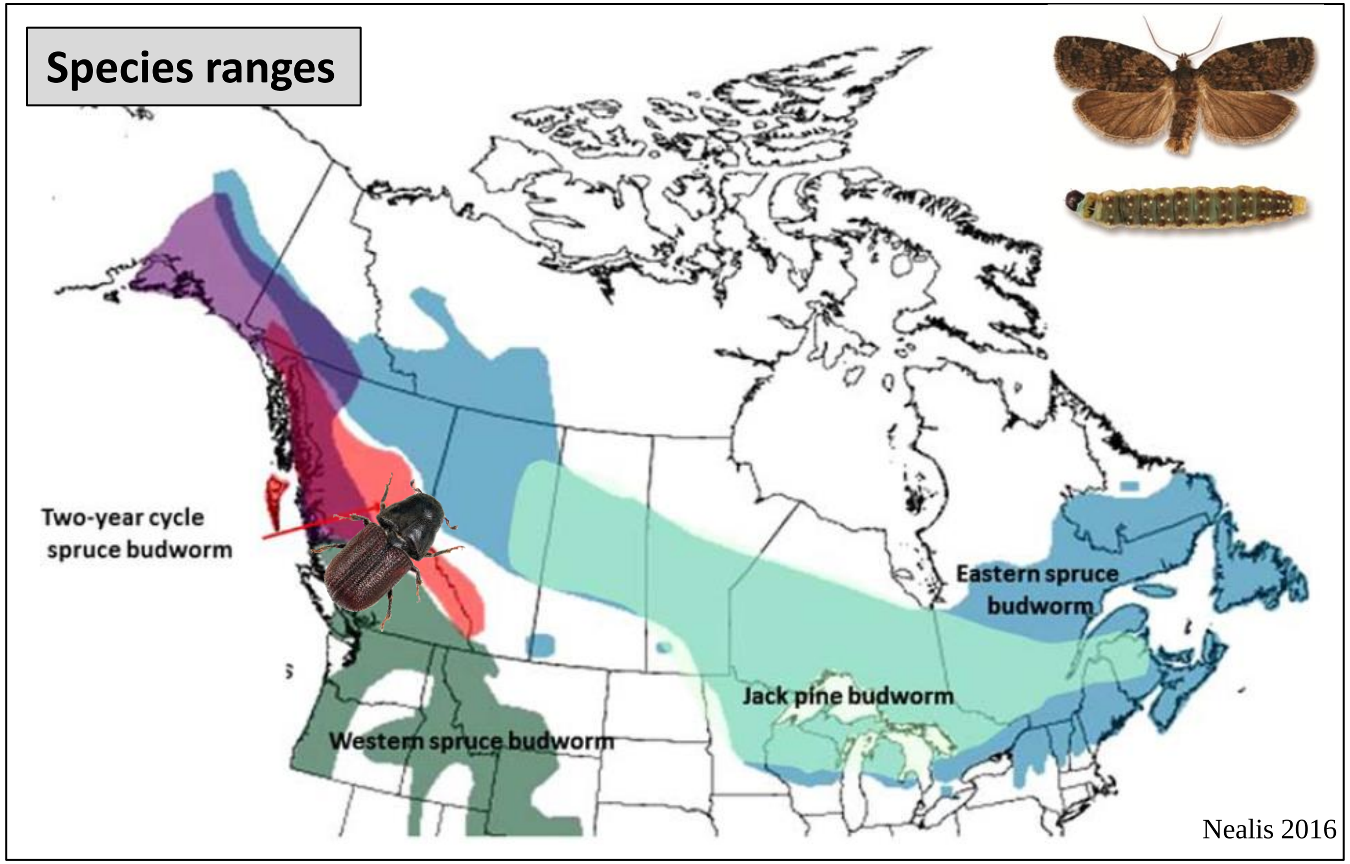
Research Themes and Objectives

- Theme 1 – Understanding fire in a changing world
  - Node 1b – Wildfire Danger
    - Obj. 1b_5 → Fuel evolution following insect outbreaks
      - Fuels following jack pine budworm (*Choristoneura pinus*) – F. Gandiaga; PDF
      - Fuels following spruce budworm (*Choristoneura fumiferana*) – K. Korkola; PhD
- Theme 4 – Managing Ecosystems
  - Node 4b – Past, present, and future fire regimes
    - Obj. 4b_2 → Historical interactions between insect outbreaks and fire
      - Spruce budworm effects on ignition probability – C. Risk; PhD
      - Mountain pine beetle (*Dendroctonus ponderosae*) effects on burn severity – D. Romualdi; MScF
      - Spruce budworm effects on burn severity – J. Goldman; PhD
      - Cumulative effects of insects and fire on boreal forest succession – J. Goldman; PhD
      - Spruce budworm effects on probability of escape and area burned – K. Korkola; PhD
    - Obj. 4b_3 → Integrated forecasting tools to model potential future climate, fire, insect interactions
      - Optimizing methods for spatio-temporal modelling of fire weather indices – C. Risk; PhD
      - …

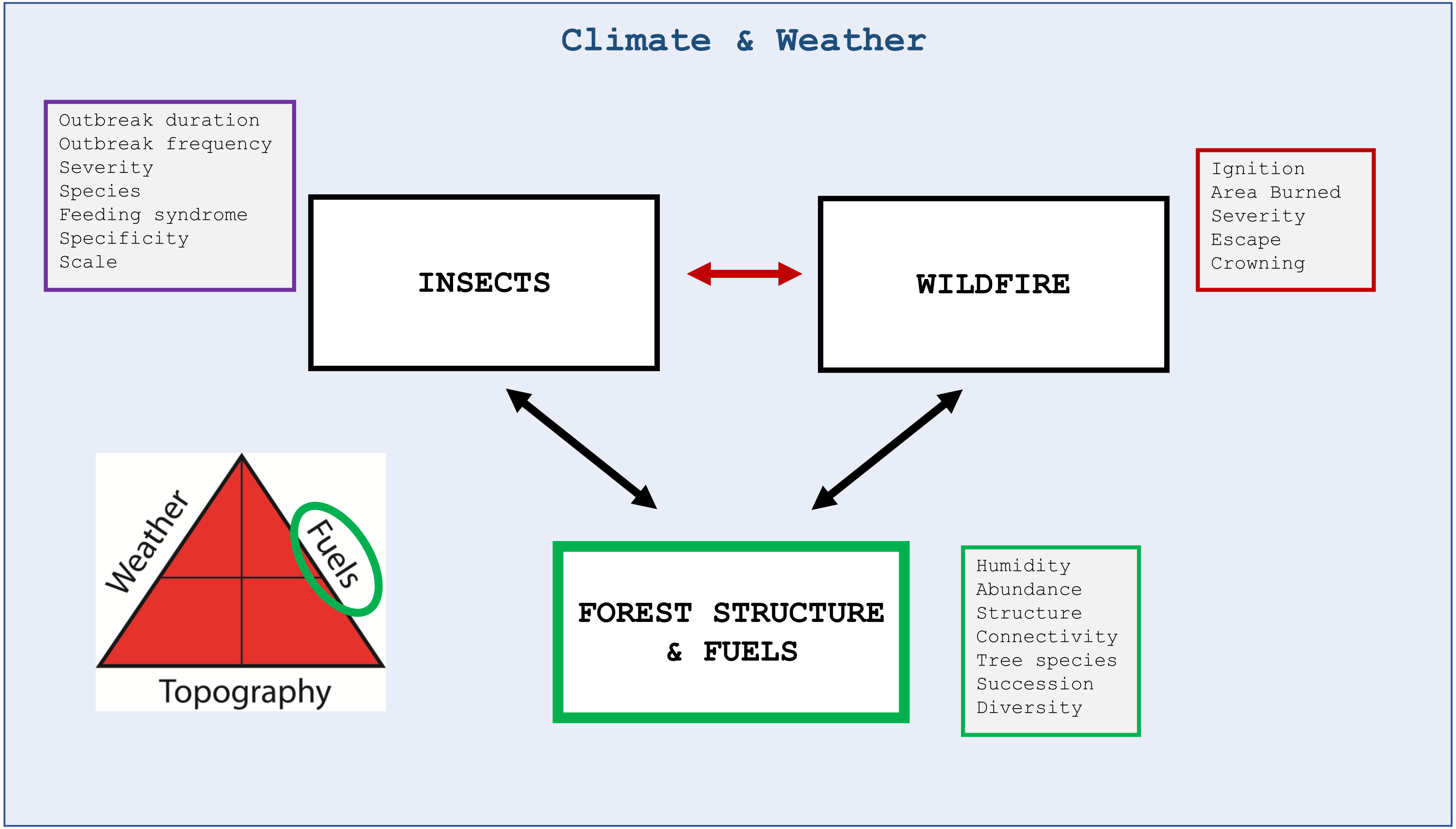

Natural Resources Canada
Ressources naturelles Canada
1980-2017
Forest Fire Perimeters
Périmètres des feux de forêt
(Forest fires / Incendies de forêt > 200 ha)
Fire data has been collected from fire management agencies.
Not all fires are shown. Locations are approximate.
Les données sur les feux ont été recueillies auprès des agences responsables
de la gestion des feux de forêt. Tous les feux ne sont pas illustrés,
et leur position est approximative.
0 500 1000 1500 2000 km
Canada


Species ranges
Two-year cycle spruce budworm
Eastern spruce budworm
Jack pine budworm
Western spruce budworm
Nealis 2016

Insect outbreaks are known to affect fuels and thus hazard, but we know little about changes through time or differences among insect species

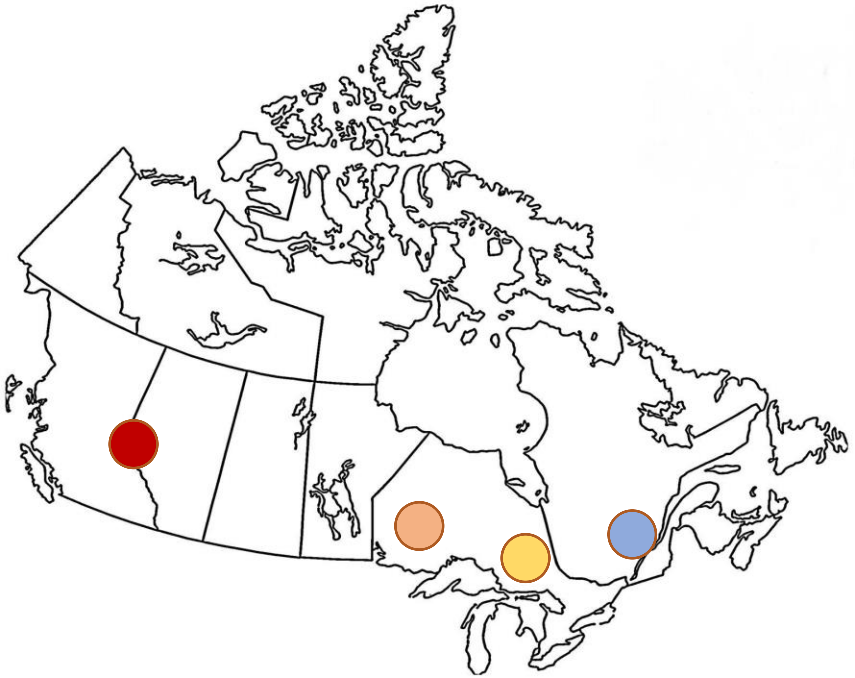
M3 - Dead Balsam Fir Mixedwood–Leafless

M4 - Dead Balsam Fir Mixedwood–Green


Climate & Weather
Outbreak duration
Outbreak frequency
Severity
Species
Feeding syndrome
Specificity
Scale
INSECTS
WILDFIRE
Ignition
Area Burned
Severity
Escape
Crowning
Weather
Fuels
Topography
FOREST STRUCTURE & FUELS
Humidity
Abundance
Structure
Connectivity
Tree species
Succession
Diversity

Ongoing Projects

	Fuel succession	P(ignition)	P(escape)	Area Burned	Severity	Succession
SBW	**K. Korkola**	**C. Risk**	**K. Korkola**	**K. Korkola**	**J. Goldman**	**J. Goldman**
JPBW	**F. Gandiaga**					**J. Goldman**
MPB	**w/ *L. Chasmer* +**				**D. Romualdi**	



Influence of spruce budworm defoliation on fire escape probability in Ontario

Kennedy Korkola

MScF

Co-supervised by Dr. Jen Beverly

Background

- Disturbance interactions
  - Spruce budworm (SBW) --> forest fires
- Fire escape models
  - Size at initial attack, topography, weather, **fuels**, fire management
- It is expected that fire escape will be increased in SBW defoliated stands
  - Fuel changes --> structure, connectivity, moisture
  - Fire activity --> ignitions, intensity, crown fires
- Fire escape is challenging to define and quantify
  - Region and goal

(Buma, 2015; Candau et al., 2018; Fleming et al., 2002; James et al., 2017; Lucash et al., 2017; Stocks, 1987; Watt et al., 2018; Watt et al., 2020)

Significance

- The interaction between SBW defoliation and forest fire escape is not understood and we lack knowledge on the consequences of these interactions
- Climate change will make this interaction worse and put pressure on fire and forest management agencies
- Findings will be useful for:
    - Providing important information on natural disturbance interactions in the boreal forest
    - Mitigating and planning for these inevitable disturbance interactions so that human activity and disturbances can continue simultaneously on the landscape.

(Podur & Wotton, 2010; Sankey, 2018)

Questions

- Does historical SBW defoliation data influence fire escape probability?
- Does the inclusion of SBW data in *randomForest* models improve their accuracy?
- How sensitive are these models to the definition of fire escape?

Methods and Preliminary Results

- Model - *randomForest*
- Predictors: fire weather indices, ecoregion, size at initial attack (IA), fire season, ignition, and **historical SBW**
- Response: escaped or contained (0/1)

- Current versions of the model show no major differences between SBW and no SBW models for the **ON definition** of fire escape
- Most important variables were size at initial attack and ISI

Threshold for fire containment	Description of containment measure
Ontario	Fire is contained at or below 4 ha in size or is 'being held' (BHE) by 1300 the following burning period
Alberta	Fire is actioned at or below 2 ha or is BHE by 1000 the next burning period
0 growth	The final size of the fire is equal to the size of the fire at initial attack
2 ha growth	The final size of the fire is no more than 2 ha greater than the size at initial attack

Next Steps

- In terms of fire escape:
  - The current results presented here do not include updated weather data
  - Also, I have only modelled fire escape using the ON definition
  - My *randomForest* model needs to be tuned using mtry and ntree
  - I expect my results to change following these adjustments

Cumulative effects of insects and fire on average burn severity

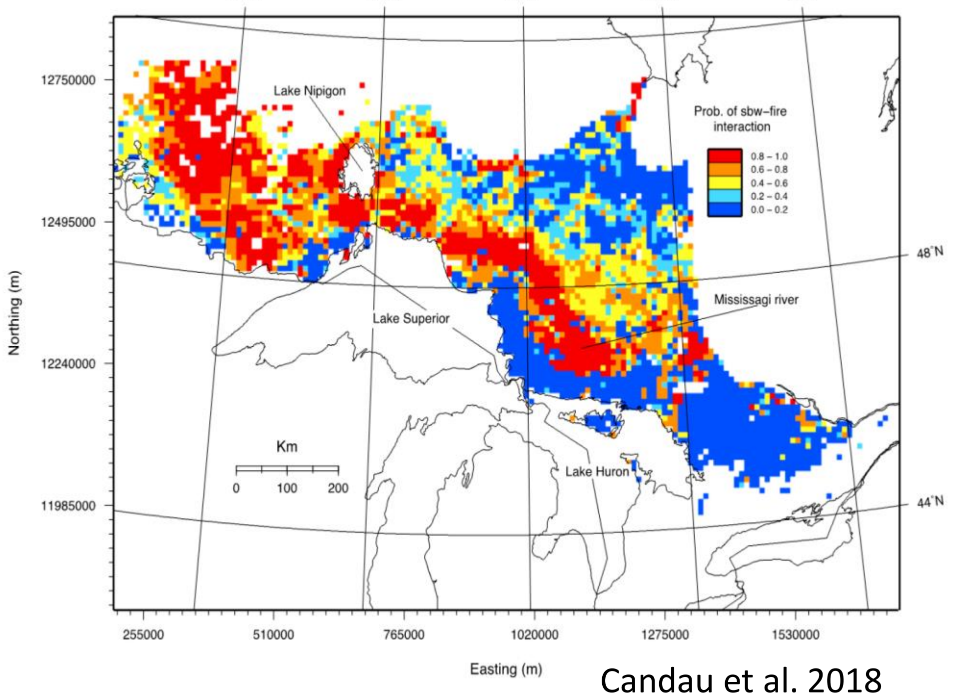
Jack Goldman

Ph.D. Student

Background

- High probability of observation SBW – Fire interactions in Ontario
- Insect and fire interactions are hypothesized to positively impact wildfire burn severity
  - SBW increase ignition likelihood, fuel buildup, crowning potential, intensity and occurrence
- Only evidence from simulation study that showed significant increases in burn severity in outbreak decades in parts of Ontario

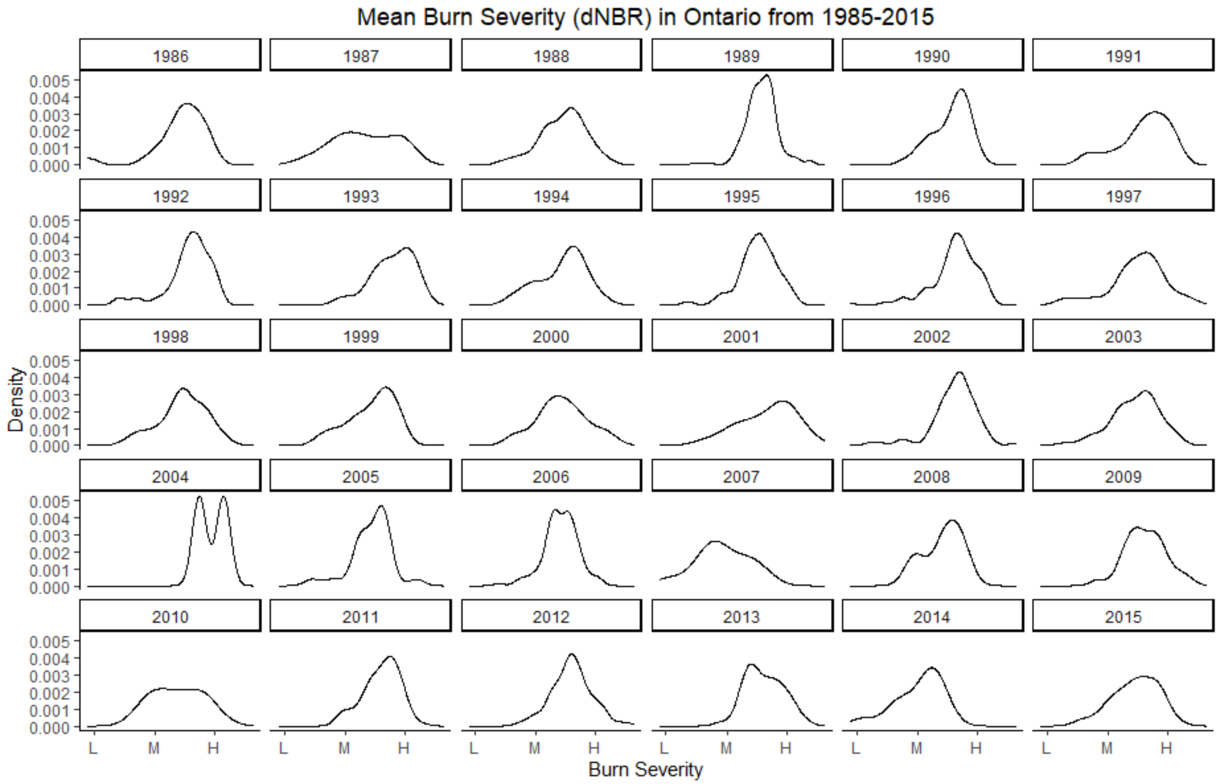
Probability of interaction between SBW and fire



Candau et al. 2018

Significance

- Burn severity is important:
  - Measured as the ecological impact of fire on vegetation and soil
  - Significantly influences the ecosystems' ability to respond
  - Long-lasting impacts on forest dynamics
- Burn severity can be highly variable year-to-year
  - Spatially heterogeneous landscapes
- Driven by fuels, topoedaphic context and fire weather
- Aid in developing emergency rehabilitation and restoration plans – post-fire
  - Estimate the likelihood of future downstream impacts

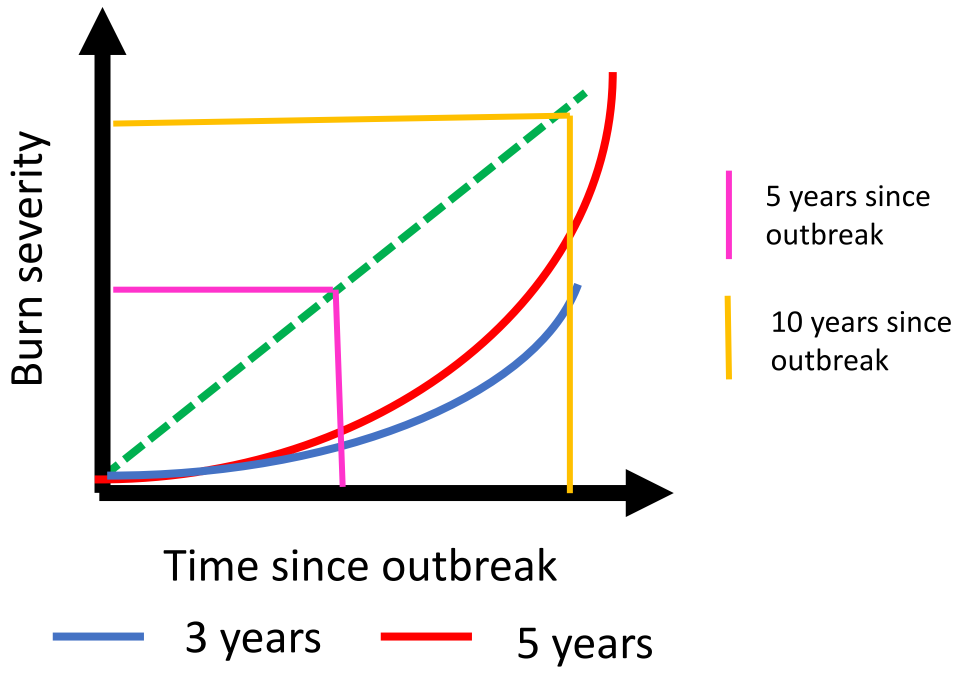


L – Low severity
M – Moderate Severity
H – High Severity

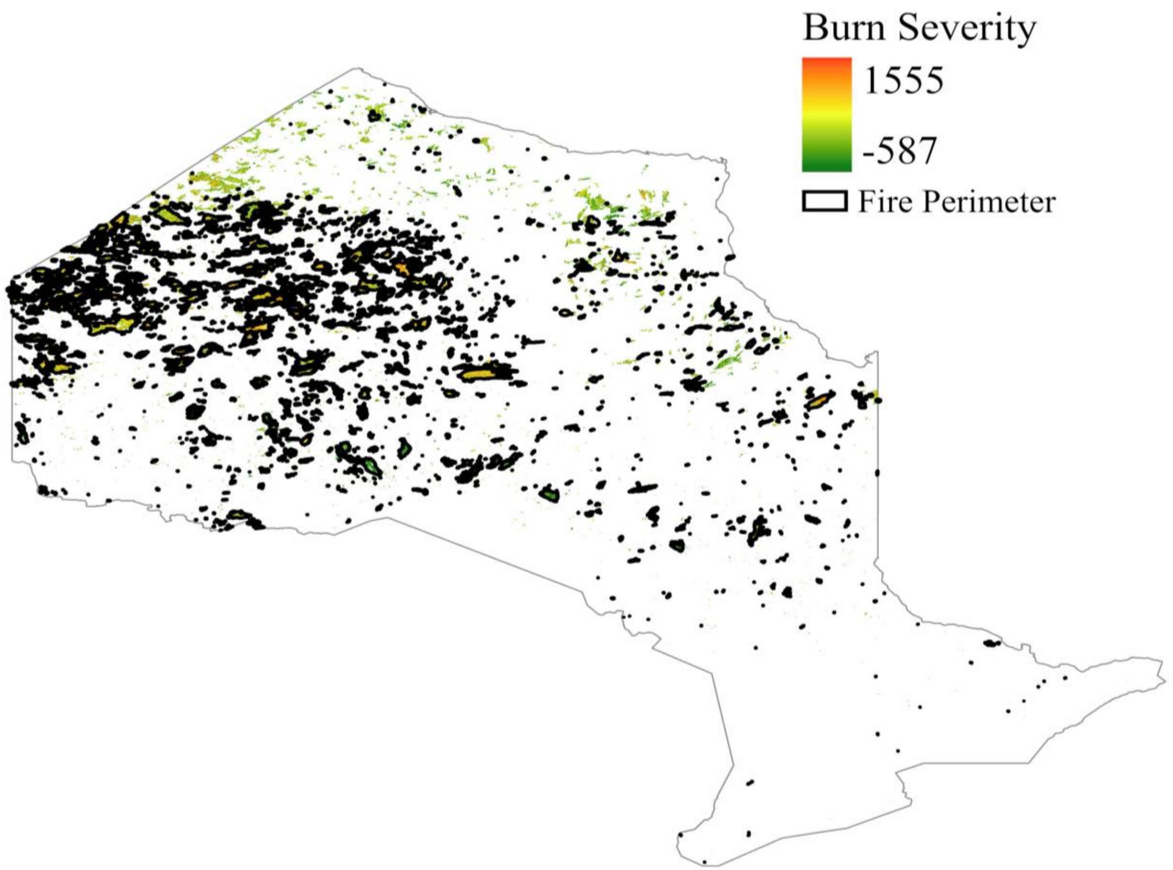
What is the effect of historical insect defoliation on average burn severity?

Expectations

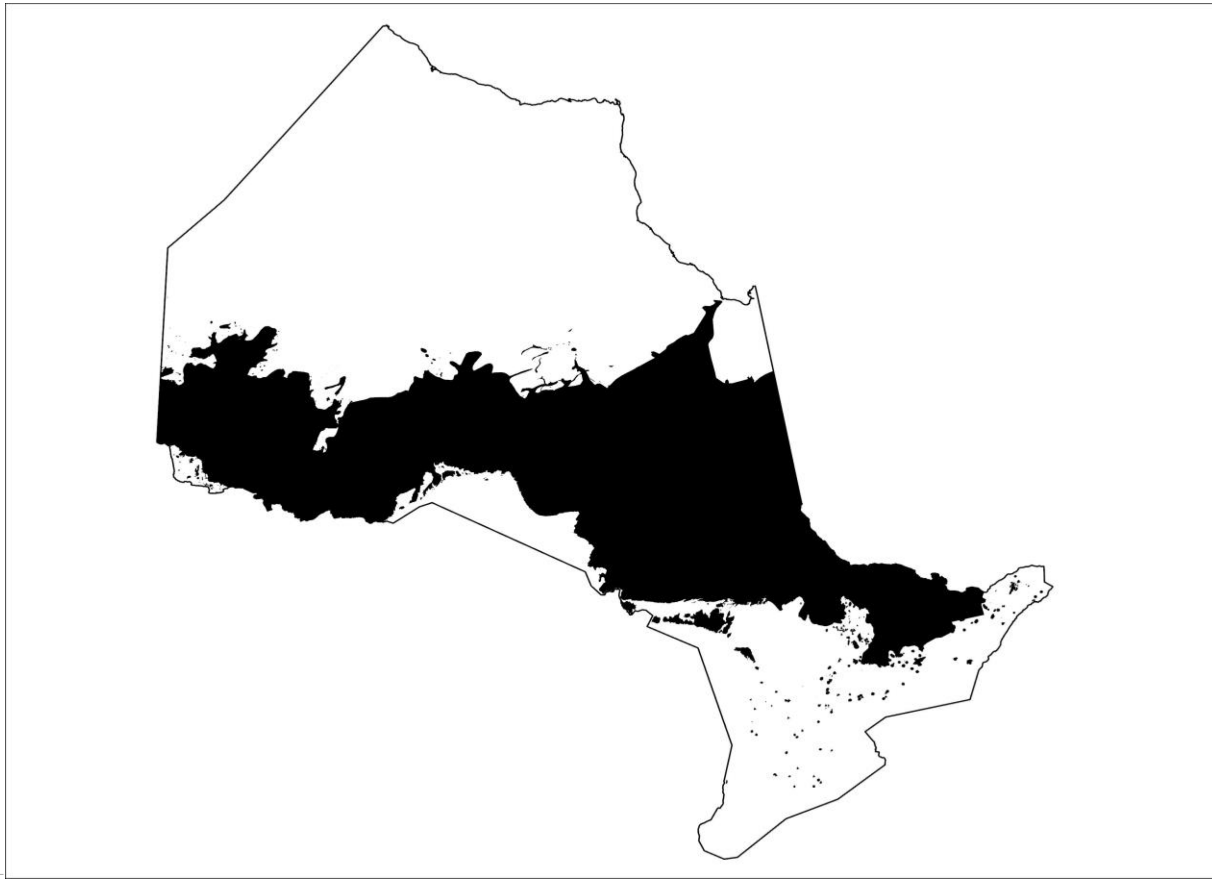
- Average burn severity will increase within fire perimeters that have experienced historical insect defoliation
- Average burn severity will increase with time since outbreak
- Average burn severity will be higher in areas experiencing more years of cumulative defoliation



Ontario Burn Severity – 1985-2015



Total area defoliated in Ontario (1970-2015)



Methods

- Mixed-effects regression model
- Compare models with or without SBW
- Response: Average burn severity
- RdNBR calculated from Canadian Landsat Burn Severity product (Guindon et al. 2021)
  - Fire Disturbance Area (OMNRF, 2021)
- Predictors: time since outbreak and cumulative year(s) of defoliation
  - Insect defoliation polygons from 1970-2015 (OMNRF, 2021)
- Additional predictors:
  - FWI – DMC, FFMC, DC, ISI, BUI (random effects)
  - D/M/Y defoliation
  - D/M/Y fire
  - Climate moisture index 3 years prior to fire (random effect)
  - Watershed (Ecoregion)

Next Steps

- Calculate RdNBR and RBR from CanLaBS product
    - Compare to dNBR on subset to see which best captures effects of defoliation
- Develop model on subset of data

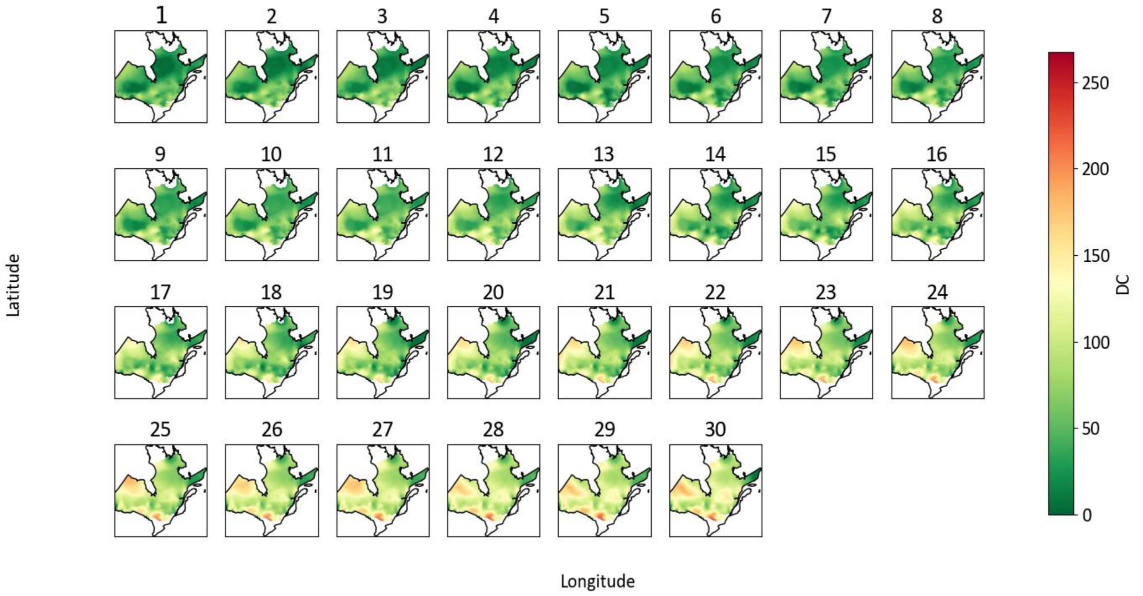
Optimal Cross-Validation Strategies for Selection of Spatial Models in the Canadian Forest Fire Weather Index System

Clara Risk

Ph.D. Student

Problem & Context

- **Overall Objective:** Calculate the Canadian Forest Fire Weather Index System codes across continuous space over long time periods for use in models requiring high-resolution data (in our case, for modeling the relationship between spruce budworm-related fuel changes and forest fire ignition)
- **Problems:**
    - Station density and distribution changes yearly, and sometimes daily or even hourly (if there is equipment failure)
    - Need methods that are computationally efficient
    - Need an effective method to choose between spatial models at a daily time scale
- **What do we need?** Continuous surfaces for: relative humidity, win speed, temperature, precipitation
- **How do we achieve this?** Spatial models (interpolation and extrapolation) that allow us to estimate the continuous surface from the weather station network



Continuous surfaces for the drought code (DC) for June 2018.

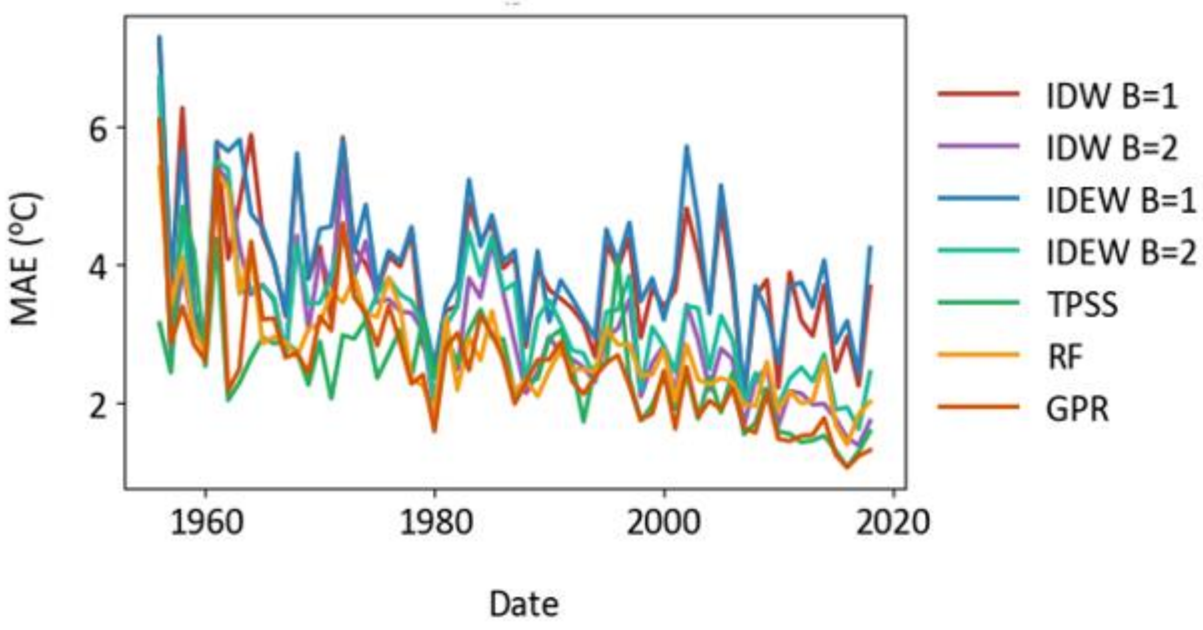
Question

- How do we evaluate the spatial models? Which one is the best?
- We evaluate with cross-validation
- This involves progressively omitting weather station(s) from the spatial model and then comparing the observed versus expected results
- The most common type in meteorology is leave-one-out cross-validation (LOOCV), where we progressively omit each weather station from the procedure, then calculate the average error for the network… but it **may be biased** due to clustered weather stations!
- **Question:** What is the difference in the error estimated by different cross-validation methods, and do they agree on the best spatial model?

Methods

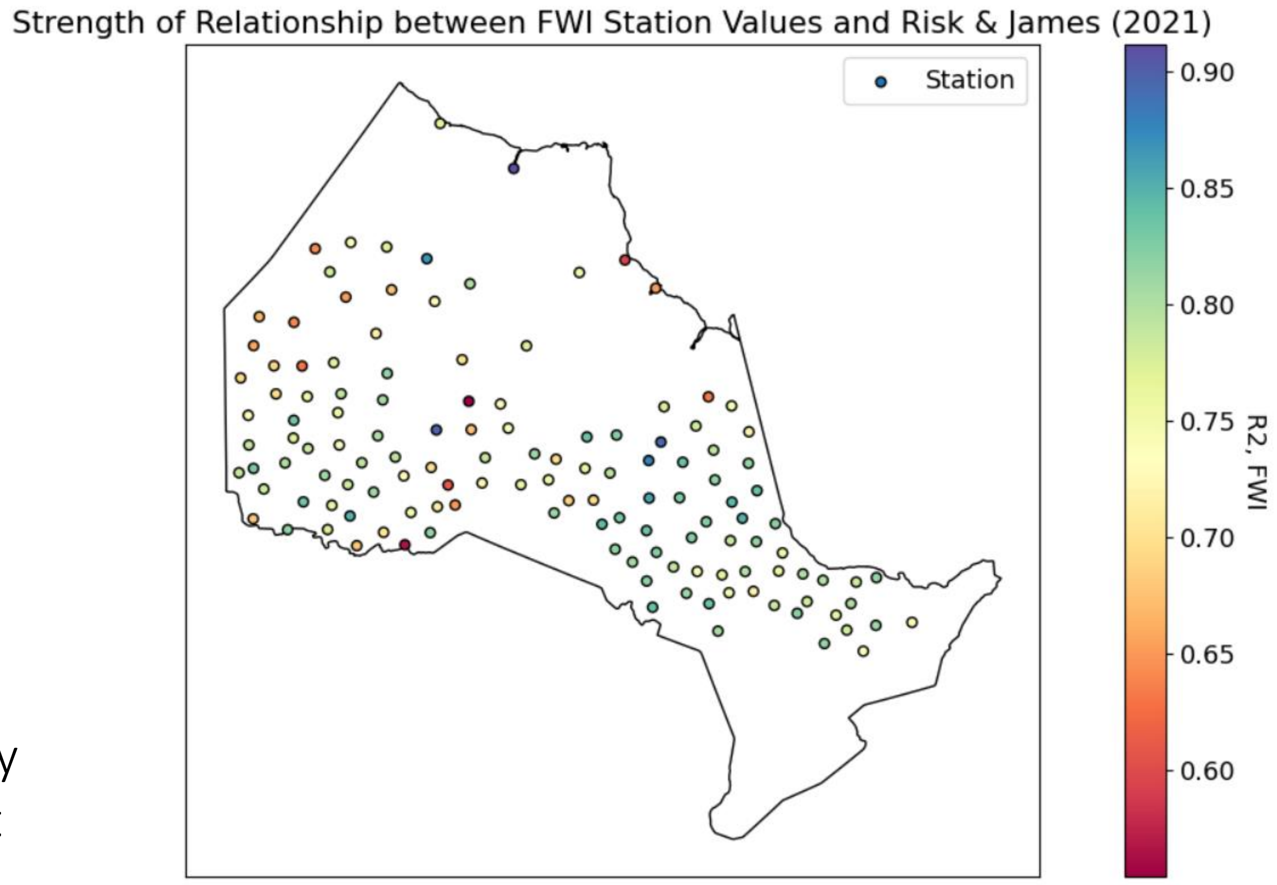
- Compared 7 spatial interpolation methods and 5 cross-validation methods
- Each combination (n=35) was evaluated using the mean absolute error (MAE) generated from cross-validation at a single test date / time (July 1 13:00 DST) for each year in the study period (1956-2018)

MAE over study period calculated using stratified shuffle-split cross-validation



Results

- LOOCV, shuffle-split, and stratified shuffle-split cross-validation select the same spatial model, although produce different error estimates
- Can use the most computationally efficient method, shuffle-split cross-validation, for selecting spatial models at a daily scale
- Results of the auto-selection procedure to create daily FWI surfaces across Ontario quality controlled against Ontario FWI Station Network with strong results



Produced by Clara Risk under Licence with the Ministry of Northern Development, Mines, Natural Resources and Forestry © Queen's Printer for Ontario, 2021

Next Steps

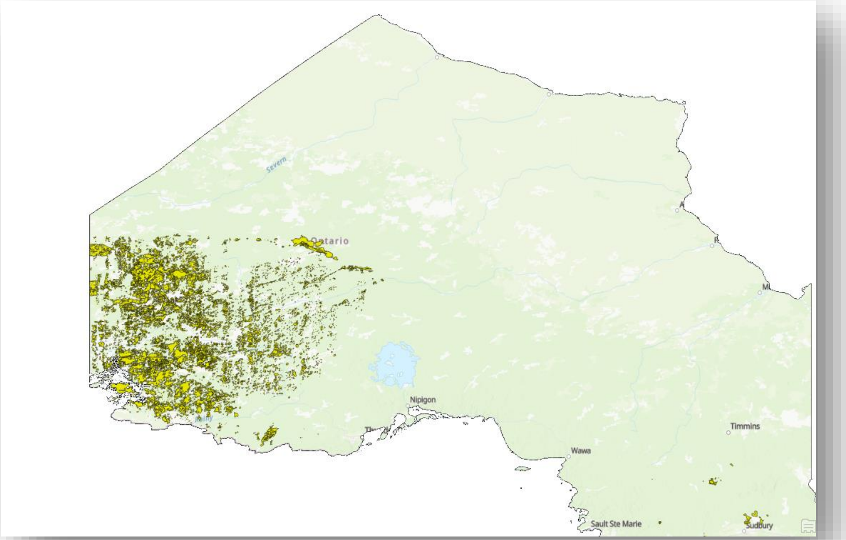
- Verify whether the FWI codes produced by the auto-selection procedure have a stronger relationship to actual fire activity compared to simply selecting a single spatial model for each weather variable
- Apply the data for use in modeling the relationship between spruce budworm defoliation and fire ignition in the eastern boreal forest (ON + QC) and how that relationship varies spatiotemporally
- Produce surfaces for use by other researchers

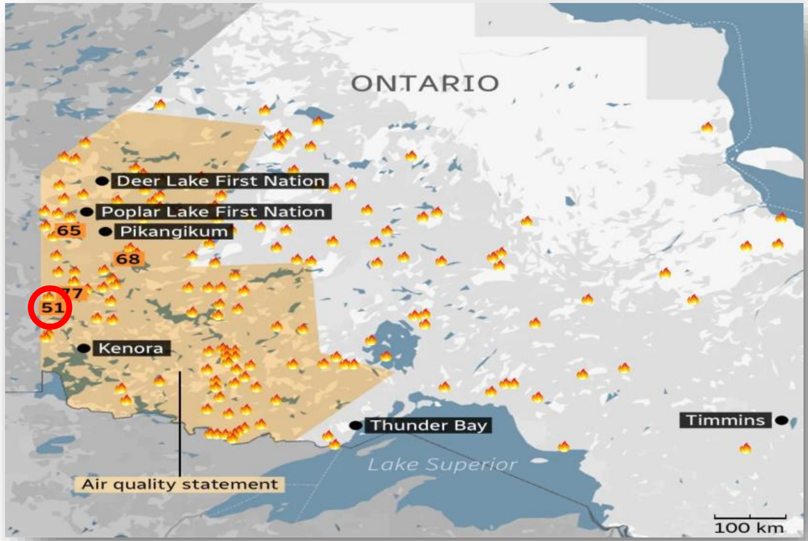
The influence of jack pine budworm (*Choristoneura pinus*) defoliation on fuels in Northwestern Ontario

Franck Gandiaga
University of Toronto

Objective

- Jack pine budworm (JPBW)
  - Native defoliator of jack pine in North America
  - Closely related to SBW – but distinct due to different outbreak dynamics (periodicity and extent of damage)
  - Ongoing outbreak in Northwestern Ontario
  - Defoliation can result in restructuring of fuels and in turn influence fire behaviour





Kenora 51
- ✓ 200 000ha burnt
- ✓ largest ever recorded in Ontario

Questions

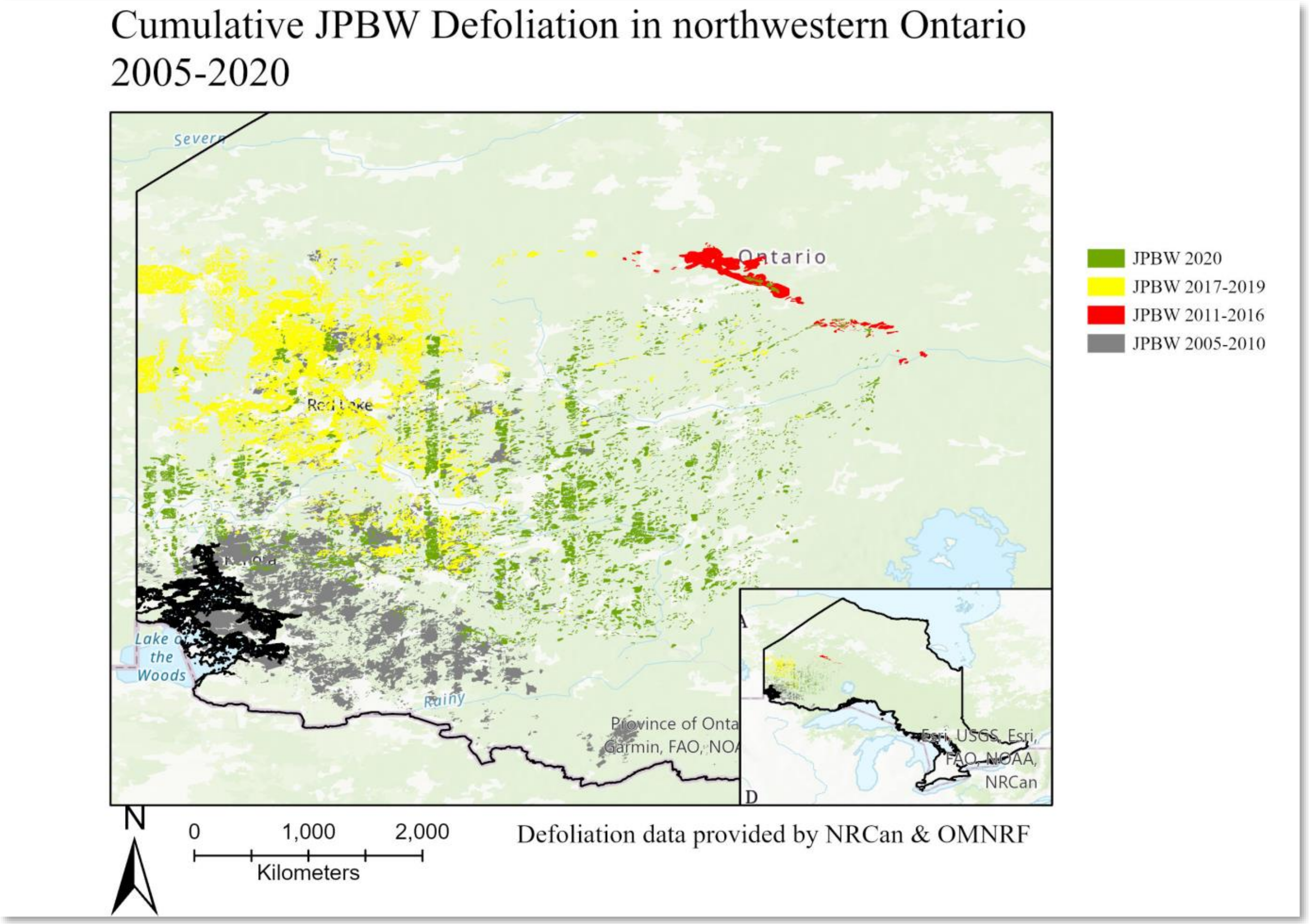
- Following a JPBW outbreak, does defoliation increase vertical fuel connectivity thus increasing fire risk?

- Does a time-lagged relationship exist between time-since-defoliation and increased fuel load/fire risk?

Methods

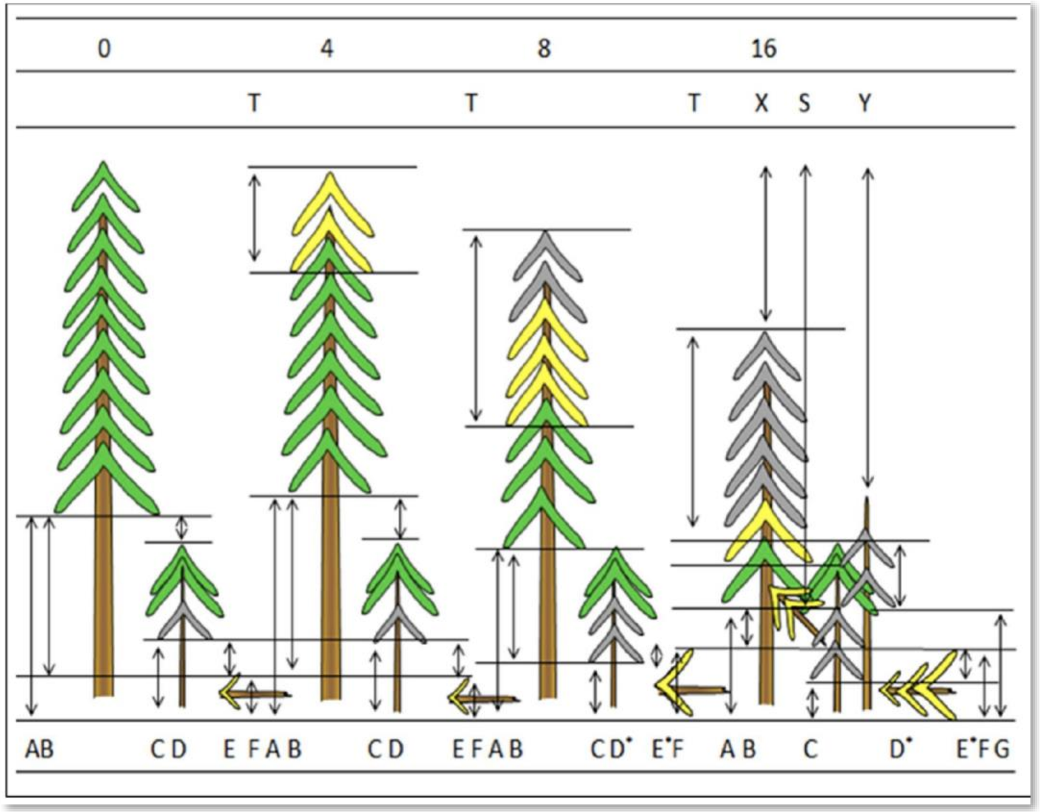
- Selected jack pine stands in different defoliation zones (2005-2020)
  - Based on time since defoliation
  - Aim: create a chronosequence (space for time substitution)

- Measured fuels available
  - Collaboration with Laura Chasmer's team and John Boucher at CFS for machine learning classification of fuels



Methods

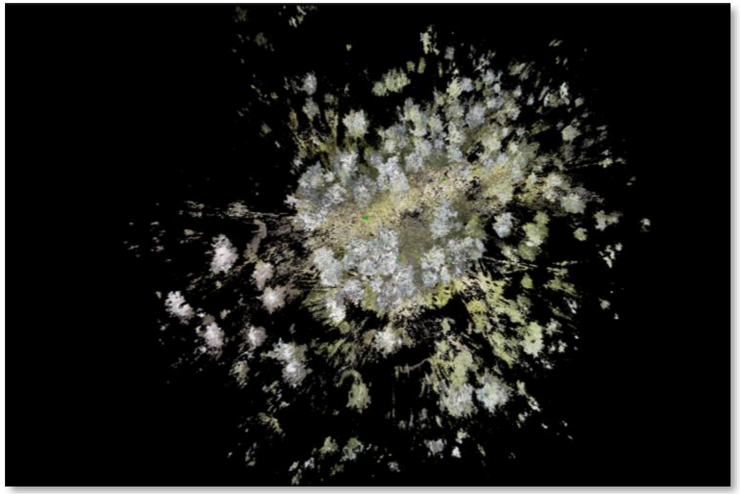
- Collection of fuel structure measurements
  - By hand:
    - Vertical fuels
    - Ground cover vegetation

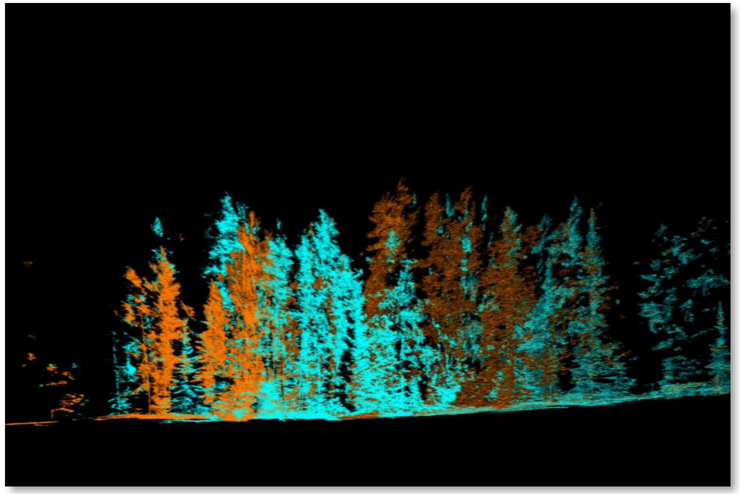


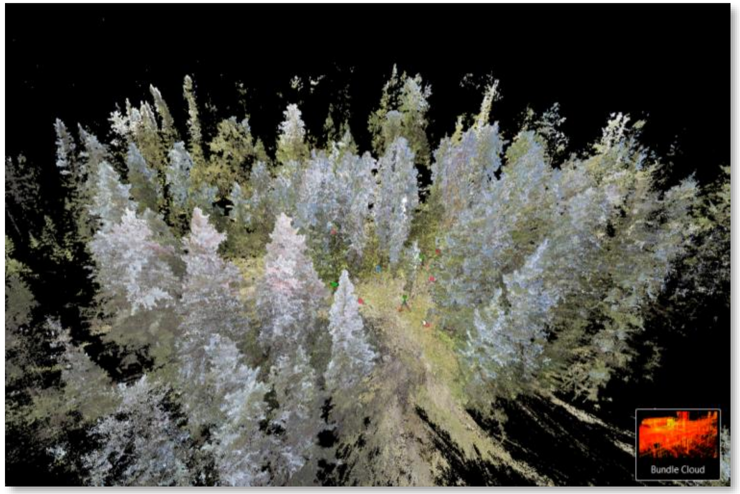
Watt et al. 2018, *Forests*, *9*(5), 256

Methods

- Collection of fuel structure measurements
  - Terrestrial Laser scanning (TLS) using a Leica BLK360
    - Overall stand structure
    - Vertical fuels:
      - ✓ machine learning
      - ✓ voxelization of the point cloud data per layer







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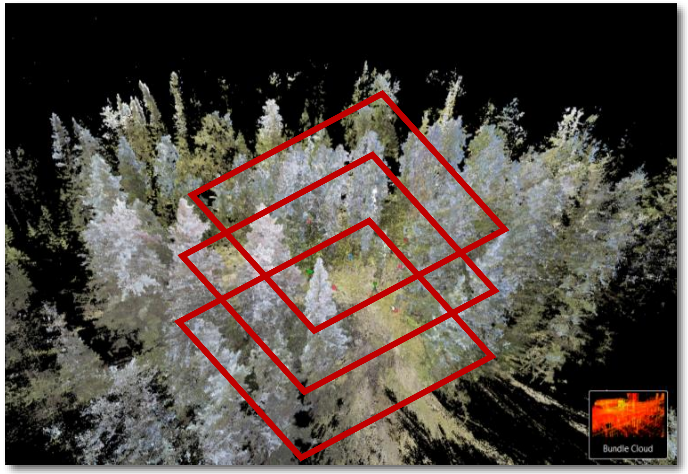
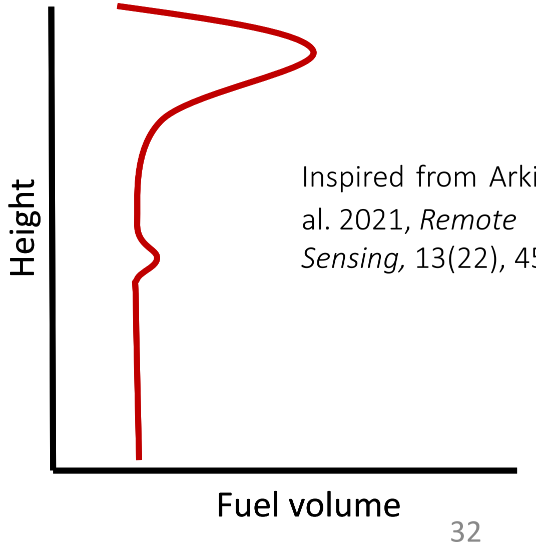




Inspired from Arkin et al. 2021, *Remote Sensing,* 13(22), 4598.

Initial results

- 4 sites measured around Kenora for a total of 25 plots (5 per site):
  - a control site
  - a 2019 - 1 year defoliation site
  - a 2020 - 1 year defoliation site
  - a 2019 – 2-year accumulated defoliation site

- By hand data is ready to be analysed

- Full 3D scans of each site are available

Next steps

- Start analyzing collected data
  - Work on the TLS data voxelization
  - Compare by hand measurements with TLS data in jack pine stands

- Plan and organize next year field season
  - Expand on the chronosequence
  - Expand towards the Red Lake area, couldn't access it in 2021 because of the fires

Meta-analysis of how mountain pine beetle outbreaks affect fire behaviour

Doriana C. Romualdi

MScF Student

2021

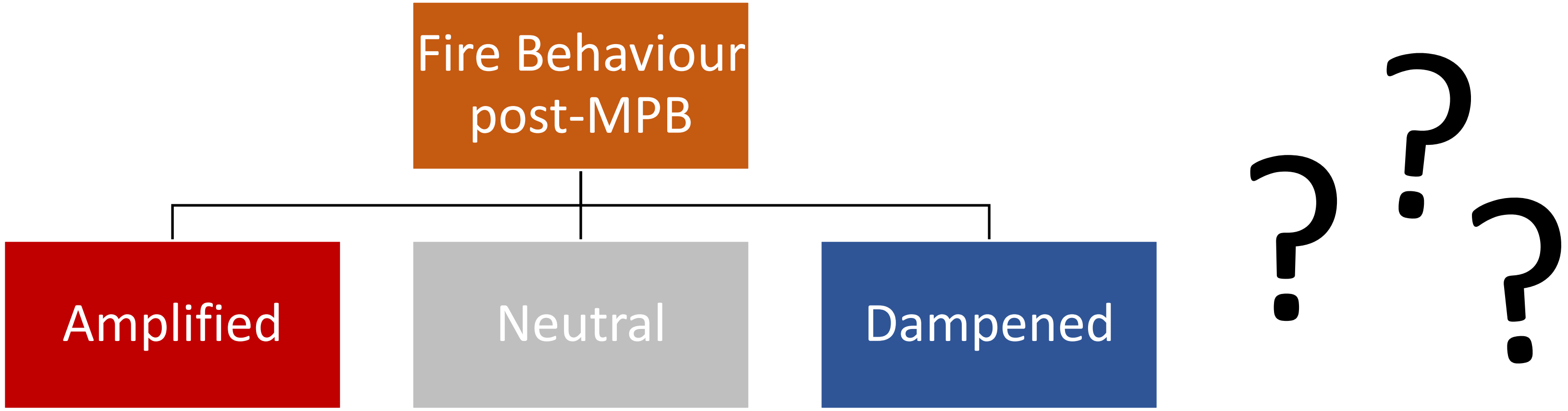
Context & Background

- Distrubance interaction: Mountain pine beetle (*Dendroctonus ponderosae*; MPB) and wildfire
- MPB is widespread across western Canada and the USA
- Alters forest stand and fuel structure over time which may influence subsequent wildfire behaviour

Safranyik & Wilson, 2006
Red-coloured pine trees indicate impacts of MPB.

Hypothesis & Purpose

- Diveristy of results regarding wildfire response to MPB outbreaks throughout the literature



Hypothesis → highly context dependent interaction

Purpose → to review literature and improve understanding regarding which environmental variables contribute most to studies' conclusion of wildfire response to MPB outbreaks

Methods

- 23 empirical publications
  → MPB effect on subsequent wildfire response
- Recorded binary presence (1)/absence (0) data for categorical indicators
- Coded wildfire behaviour response
  - Positive (+1)
  - Null (0)
  - Negative (-1)
- Summarized using PCA

Table 1: Categories analysed

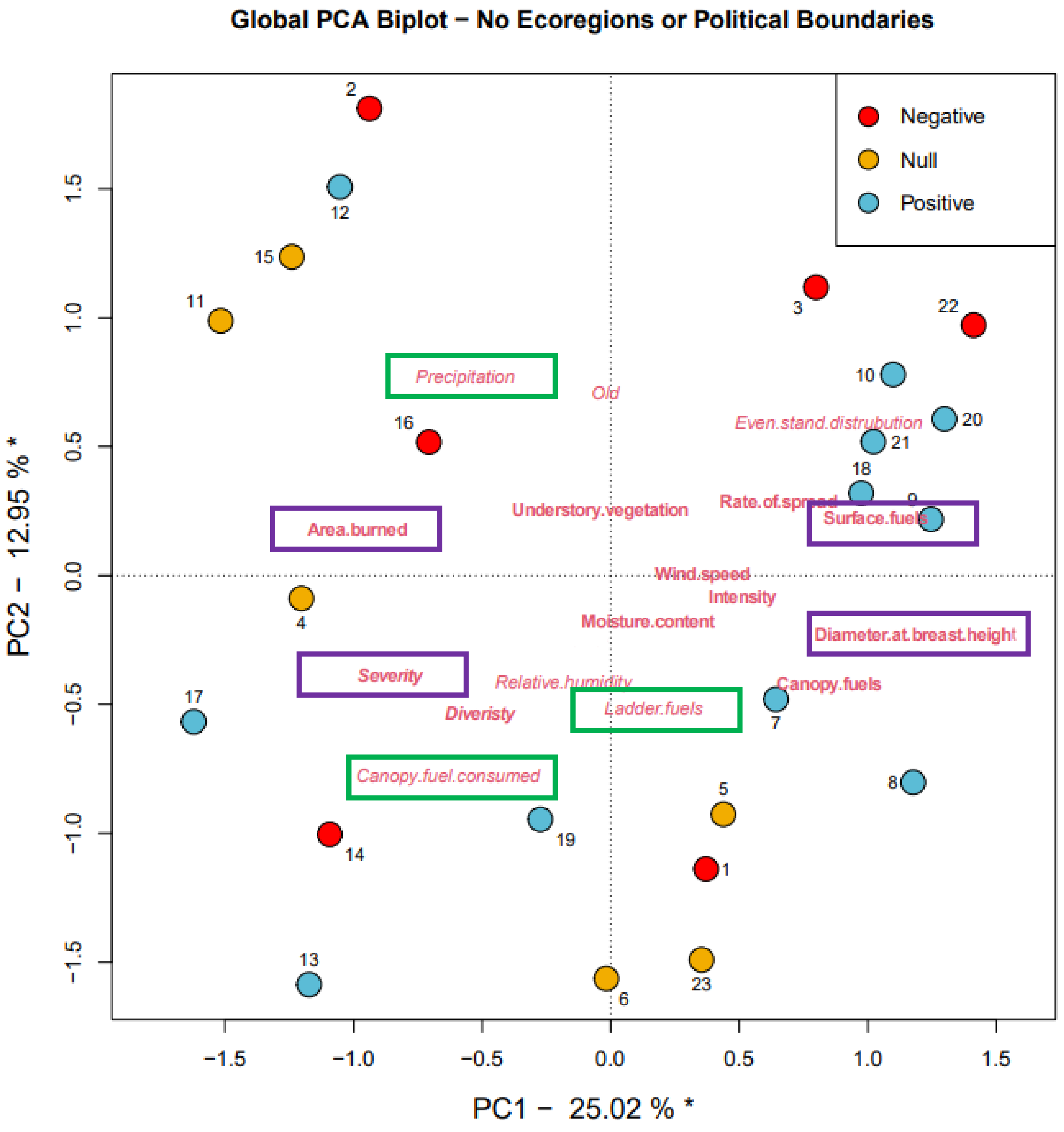
Main categories analysed
Time Since Beetle (TSB) stage
Weather Conditions
Fuel & Stand Characteristics
Fire Behaviour Characteristics
Ecoregions (NA LVL III)
Political Boundaries

Table 2: Subset of TSB data

Study	Time Since Beetle (TSB) stage			
	Green (unattacked)	Red (1-2 years)	Gray (3-5 years)	Old (10-40 years)
1	0	0	1	0
2	0	1	1	1
3	0	1	1	0
4	1	1	1	0
5	0	1	1	0
6	0	1	1	0
7	0	1	0	0
8	0	1	0	0
9	1	1	1	1
10	0	0	1	0
...				

Initial Results

- No clear interpretation of PCA axes
  - Axis 1 ~ fire behaviour --> fuels
  - Axis 2 ~ weather --> fuels
- No clear pattern to fire behaviour consequences of MPB
- Slight grouping of positive wildfire response studies associated with wildfire behaviour attributes, and fuel characteristics in top right quadrant
- Study locations excluded as they tend to overfit the model (unique location for each study)
- Scale of analysis (stand vs landscape) may be influencing results

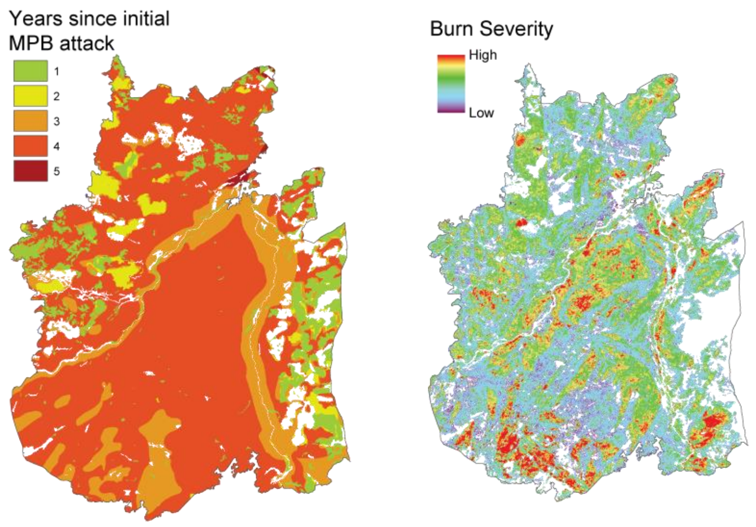


Conclusion

- Wildfire response to MPB outbreaks is unclear
- No clear pattern in where, when, and how MPB outbreaks affect fire

Next steps!

- MScF project will investigate the effects of spatial legacies left behind by MPB outbreaks on wildfire severity (**RdNBR**) in Canadian lodgepole pine forests (British Columbia and Alberta)
- Additional support from fRi
- Working with Dr. M-A. Parisien (CFS)



Extent, severity, and associated MPB history of a lightning-caused wildfire near Nuntsi Provincial Park (BC). Date: July 20, 2009; Final Size 67743 ha.

Outbreaks, fuels, and wildfire …

- Goal is to merge these empirical relationships among insect outbreaks, timing, fuels, and fire behaviour in a simulation platform
- Downstream application in mechanistic (e.g., Burn P3, CFIS, FBP) and Landscape level (pattern based) simulators (e.g., Spades, SELES, LANDIS2)
- Implementation will allow us to ask further questions about the complex interactions among forest disturbances and climate change, and their consequences for **forest health** and resilience in the future

SBW-killed forest

Thank you

- Jared Haney (UofT)
- Kendriah Pearse (UofT)
- Julian Wittische (UdeM)
- Jon Boucher (CFS)
- Anne Cotton-Gagnon (CFS)
- Laura Chasmer (ULeth)
- Chris Hopkinson (ULeth)
- Mat Corbett (OMNRF)
- Colin McFayden (OMNRF)
- Marc-Andre Parisien (CFS)
- Chris Stockdale (CFS)

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