Wildfire, Fuels, and Climate Change in Michigan’s Jack Pine-Dominated Ecosystems

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Northern Lower Michigan
Northern Lower MI - Grayling Outwash Plain

- High elevation outwash plain
  - Ice-contact features
  - End moraines
  - Glacial meltwater streams

- Inland from Great Lakes
  - Lower winter temperatures

- Excessively drained sands
  - Supports jack pine

Albert et al. 1995
Jack pine

*(Pinus banksiana* Lamb.)*

- Grows on dry, infertile soils
- Mature trees:
  - 17-20 m tall, 20-25 cm dbh
- Range:
  - Lake States, Canada
- Adapted to fire
  - Leaf litter flammable, ladder fuels
  - Serotinous cones
  - Germinates on bare mineral soil

Rudolph, 1958
Background: Fire Regime

Fire Type - level where fire burns: ground, surface, crown

Fire Intensity - length of flame/amount of energy produced

Fire Severity - effect of fire on soil or vegetation

Fire Frequency - how often a burn occurs

Background: Fire Regime

Fire Return Interval - average number of years between fires for a given area

Fire rotation/Fire cycle - length of time required to burn over an area equal to that under consideration

Fire Regime of jack pine-dominated ecosystems

- Type: stand-replacing crown fires
- Fire rotation 59 years
  - Cleland et al, 2004
- Fire return interval 12-60 years
  - Simard and Blank, 1982
- Produces typical stand structure in the area
Management for Kirtland’s warbler (*Setophaga kirtlandii* Baird) habitat

- Kirtland’s warbler breeding habitat
  - 5-23 year old trees
  - 20-60% canopy cover
  - Patchy, with openings
  - Probst and Weinrich, 1993

- Management Actions
  - Nearly 80,000 ha
  - Plantations
  - Prescribed fire

Figure: Birds of North America database
Mack Lake Burn

- May 5, 1980
- Escaped prescribed burn
- 24,000 acres (~9,700 ha)
- Consumed 270,000 tons of fuel
- 1 person killed, 44 buildings destroyed

Simard et al. 1983
Landscape Ecosystems of Mack Lake Burn

Walker et al., 2003
Jack pine forests in Mack Lake

Dominant trees:
- jack pine
- northern pin oak

Also:
- red maple, quaking aspen, big-toothed aspen, red pine, white oak
Why study fuels?

- Ecological structure & function
  - Little known how fuels change with succession
- Fuel Management
  - Hazardous fuels reduction
  - Predicting wildfire behavior
Fuel Types

- Fine Woody Debris
  - 1-hr
  - 10-hr
  - 100-hr
- Coarse Woody Debris
  - 1000-hr
- Litter
- Duff
- Ground Vegetation
- Understory, Overstory Vegetation

<table>
<thead>
<tr>
<th>Dead woody class</th>
<th>Piece diameter</th>
<th>Piece diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>inches</td>
<td>cm</td>
</tr>
<tr>
<td>DWD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FWD</td>
<td>1-hr</td>
<td>0–0.25</td>
</tr>
<tr>
<td></td>
<td>10-hr</td>
<td>0.25–1.0</td>
</tr>
<tr>
<td></td>
<td>100-hr</td>
<td>1.0–3.0</td>
</tr>
<tr>
<td>CWD</td>
<td>1,000-hr and greater</td>
<td>3.0 and greater</td>
</tr>
</tbody>
</table>
Importance of Coarse Woody Debris (CWD)

- Habitat for insects, bacteria, fungi, invertebrates
- "Nurse logs" for tree seedlings
- Source of carbon to forest floor
- Source of CWD for rivers

Tinker and Knight, 2004
Tinker and Knight, 2004

Brais et al, 2005
Importance of Litter and Duff

- Nutrient-rich
- Habitat for micro and mesofauna
  - Lutes and Keane, 2006
- Unburned, moist duff = layer of insulation
- Thick, dry duff = damage to mineral soil
  - Hartford and Frandsen, 1992
Fuels & Succession in Mack Lake Burn

Question:
How will vegetation structure and fuels change throughout post-fire succession?
Hypotheses

- As the forest develops post-burn, we expect
  - More canopy coverage mid-succession
  - Decrease in jack pine density
  - Decrease in coarse woody debris
  - Thicker litter and duff layers
Sampling Sites
Data Collected

- Vegetation Plots:
  - Overstory & Understory Tree Density, DBH & species
  - Groundcover abundance
  - Stand height

- Fuel Transects
  - Modified FIREMON sampling method (Lutes & Keane, 2006)
Sampling Design
Fuel Data Collected

Along each transect:
- Aspect & Slope
- 10 & 20 m marks
  - Litter, Duff
  - Ground vegetation
  - Tallest live trees

- Fine woody fuels
  - 1-hr
  - 10-hr
  - 100-hr

- Coarse woody fuels (1000-hr)
  - 5-25 m decay class & diameter
Sight along one edge of the measuring tape
Field Tools
Forest Succession

Changes in stand density of jack pine

Changes in seedling density of common tree species over time
Canopy Cover

![Canopy Cover Image]

- **1986**: Average % Canopy Cover
- **1996**: Average % Canopy Cover
- **2017**: Average % Canopy Cover
Coarse Woody Debris (CWD)

<table>
<thead>
<tr>
<th>Decay Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>All bark intact, most twigs present, hard when kicked.</td>
</tr>
<tr>
<td>2</td>
<td>Some bark and branches missing, still hard when kicked.</td>
</tr>
<tr>
<td>3</td>
<td>Most bark and branches are missing, still hard when kicked.</td>
</tr>
<tr>
<td>4</td>
<td>Most bark and branches are missing, soft when kicked.</td>
</tr>
<tr>
<td>5</td>
<td>Log in contact with ground, easy to kick apart.</td>
</tr>
</tbody>
</table>
### Landform Type and CWD

#### Table:

<table>
<thead>
<tr>
<th>Landform</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Low elevation; glacial meltwater drainage channels; infertile. <em>(Very dry, nutrient-poor, very cold)</em></td>
</tr>
<tr>
<td>4</td>
<td>Low elevation; pitted outwash plains; infertile. <em>(Very dry and nutrient-poor; cold).</em></td>
</tr>
<tr>
<td>5</td>
<td>High elevation; outwash plains of varying fertility. <em>(Moisture and nutrients variable; warmer).</em></td>
</tr>
</tbody>
</table>
Fine Woody Debris (FWD)
Litter and Duff

Yermakov and Rothstein, 2004
Height and Cover of Ground Vegetation
Summary of Mack Lake Fuels

- With time since fire,
  - Overstory density increased, while understory density decreased
  - Overall density of jack pine decreased
  - Litter and duff increased
  - CWD has decreased
Forest Vegetation Simulator (FVS)

- Models forest growth
  - due to natural succession, disturbance, or specific management action
- Free and available at [https://www.fs.fed.us/fvs/software/complete.php](https://www.fs.fed.us/fvs/software/complete.php)
  - Lake States (LS) geographic variant
  - Fire and Fuels Extension (FFE)
**Comparison to pre-Mack Lake**

Table 4b.—Range of fuel loadings and consumption for jack pine stands (4- to 6-inch d.b.h., 400 to 1,200 trees/acre)

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>After</th>
<th>Consumed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tons/acre</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shrubs, herbaceous</td>
<td>0.0–2.4</td>
<td>0.0–0.2</td>
<td>0.0–2.1</td>
</tr>
<tr>
<td>Litter</td>
<td>.2–5.3</td>
<td>.0</td>
<td>.2–5.3</td>
</tr>
<tr>
<td>Duff</td>
<td>4.2–18.0</td>
<td>1.4–11.7</td>
<td>.8–7.8</td>
</tr>
<tr>
<td>Wood¹</td>
<td>4.4–5.0</td>
<td>1.6–5.3</td>
<td>.0–2.8</td>
</tr>
<tr>
<td>Foliage²</td>
<td>1.0–3.8</td>
<td>0.0–3.8</td>
<td>.0–3.8</td>
</tr>
<tr>
<td>Measured range³</td>
<td>11.0–27.2</td>
<td>4.5–16.6</td>
<td>.0–19.1</td>
</tr>
</tbody>
</table>

¹Average for all species (12 samples).
²Based on Brown’s (1965) equation (not including branchwood).
³Range of individual plots — not the range columns.
⁴The highest woody fuel loading was measured on a burned plot.

Simard et al, 1983
Future Research

- Comparing across ecosystems
  - Effects of soils, landform, elevation, slope, aspect
- Modeling 1986 fuel data in FVS
  - Were fire effects as predicted since fire?
- Modeling future fire behavior
Relationship to slope
Variability in Stand Structure
Can jack pine barrens mediate wildfires under various climate scenarios?

Fig. 5 Persistence categories shown for the various cover types. Y-values represent the total area in each persistence class summed for all four dates in the aerial photo sequence. 

Grossmann & Mladenoff, 2007
Questions and hypotheses

• Q₁: How is jack pine barrens distribution affected by wildfire severity?
  H₁: Higher severity fires will yield more, larger barrens

• Q₂: How might climate change affect fire severity?
  H₂: Fire severity will increase, and more severe climate scenarios will have greater effects

• Q₃: How might climate change affect the distribution of pine barrens in the region?
  H₃: Climate change will increase the coverage of barrens, and more severe climate scenarios will have greater effects
LANDIS-II: model fires and resulting cover types to investigate effects of climate change on barrens coverage.
Climate Scenarios

– Historical: interpolated data ca. 1900
– Current: averaged 2007-2017
– Future: GCMs projected to 2099

• CanESM2 - Canadian Centre for Climate Modeling and Analysis
• CCSM 4.0 - National Center of Atmospheric Research, USA

http://kiwi.atmos.colostate.edu/cmmap/learn/modeling/whatIs2.html
Representative Concentration Pathways

- RCP 2.6 – CO₂ mitigation scenario
- RCP 4.5 – reduced emissions scenario
- RCP 8.5 – business as usual, fossil fuel intensive

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Minimum Temperature (°C)</th>
<th>Maximum Temperature (°C)</th>
<th>Monthly Precipitation (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Historical</td>
<td>-0.5</td>
<td>11.8</td>
<td>6.6</td>
</tr>
<tr>
<td>Current</td>
<td>0.3</td>
<td>12.8</td>
<td>5.7</td>
</tr>
<tr>
<td>CanESM2 – rcp2.6</td>
<td>3.7</td>
<td>15.0</td>
<td>7.7</td>
</tr>
<tr>
<td>CanESM2 – rcp4.5</td>
<td>3.5</td>
<td>15.6</td>
<td>7.4</td>
</tr>
<tr>
<td>CanESM2 – rcp8.5</td>
<td>5.9</td>
<td>18.6</td>
<td>8.5</td>
</tr>
<tr>
<td>CCSM4 – rcp2.6</td>
<td>1.5</td>
<td>14.0</td>
<td>5.9</td>
</tr>
<tr>
<td>CCSM4 – rcp4.5</td>
<td>2.2</td>
<td>15.3</td>
<td>6.7</td>
</tr>
<tr>
<td>CCSM4 – rcp8.5</td>
<td>5.5</td>
<td>19.0</td>
<td>6.7</td>
</tr>
</tbody>
</table>
Climate Effects: Fire Severity

![Boxplot and bar chart showing fire severity across different scenarios and models, with comparisons between historical and current conditions.](image)
Climate Effects: Cover Type
CCSM Model

Graph showing the percent cover of different vegetation types under historical and current conditions, as well as projections for CCSM models 2.6, 4.5, and 8.5.
Climate Effects: Cover Type
CanESM Model

[Barren, Young Jack Pine, Mature Pine, Mixed Pine, Deciduous]
Climate Effects: Fire Regime

Number of Fires

Historical | Current | CCSM 2.6 | CCSM 4.5 | CCSM 8.5 | CanESM 2.6 | CanESM 4.5 | CanESM 8.5
Climate Effects: Barrens Distribution

Fuel Types at Year 200
Historical Climate

Fuel Types at Year 200
Current Climate

Fuel Types:
- Young Jack Pine
- Barrens
- Mixed Pine
- Deciduous
- Mature Jack Pine
- Lowland Wet
Climate Effects: Barrens Distribution
Climate Effects: Barrens Distribution

Fuel Types at Year 200
CANESM 2.6 Climate

Fuel Types at Year 200
CANESM 4.5 Climate

Fuel Types at Year 200
CANESM 8.5 Climate
• Climate change may cause unpredictable changes in the region

• Severe fires may increase, but barrens may not necessarily
Management Implications

- Barrens are similar in structure to fuel breaks, but may be reduced due to climate change.
- Including barrens in management practices may become even more important.
Conclusions

• May be difficult to predict future outcomes using historical references
  • Novel conditions imposed by climate change
  • Interactions may be especially difficult to predict
• Highlights importance of long-term, field-based studies
THANK YOU

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