Fuel loads, fire severity, and tree mortality in Florida Keys pine forests

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The Pine Rocklands of South Florida

- Subtropical forests dominated by slash pine (*Pinus elliottii* var. *densa*)
- An endangered ecosystems
- Rich in flora including many endemic plant taxa.

The Pine rocklands in the Lower Florida Keys:

- Habitat of the endangered Key Deer (*Odocoileus virginianus clavium*)
The Pine rocklands and fire:

- Fire is important in shaping the structure and function of ecosystems.
- The endemic herb species require fire for their existence, survival, and reproduction.

Without fire:
- succession towards a closed hardwood canopy
- loss of the characteristic pineland herb flora

Fire behavior depends on:
- Stand age & fuel availability
- Understory fuel types
- Season of prescribed burning
A conceptual model showing hypothetical relationships among fuel loads, fire behavior and tree mortality.
<table>
<thead>
<tr>
<th>Site</th>
<th>Plot code</th>
<th>Burn Year</th>
<th>Post-burn Yr-1</th>
<th>Post-burn Yr-2</th>
<th>Post burn Yr-3</th>
<th>Post-hurricaneYr3</th>
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<tbody>
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<td></td>
<td>OS</td>
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<td>OW</td>
<td>1998 (W)</td>
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<td>2001</td>
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<td>IS</td>
<td>1999 (S)</td>
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<td>IW</td>
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<td>2001</td>
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<td>DS</td>
<td>1999 (S)</td>
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<td>DW</td>
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<td>2001 (S)</td>
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<td>LW</td>
<td>2001 (S)</td>
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<td>Buttonwood</td>
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<td></td>
<td>BW</td>
<td>2001 (S)</td>
<td></td>
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</tbody>
</table>
Methodology

**Fuel estimates**

- **Shrub and Saplings (Ht >1m, dbh <5 cm)**
  - Shrubs and Pine – allometric equations for height and crown area or dbh
  - Palms – Crown area and number of leaves

- **Ground layer (Height <1m)**
  - Harvest method

**Fire severity**
- Char height
- Scorch percent

**Fuel estimates**

- **50 m² shrub plots**
  - Radius = 4 m

- **Ground fuel plot**
  - 0.25 m²

**Ground layer (Height <1m)**
- Harvest method
Results

Understory fuels

<table>
<thead>
<tr>
<th>Sites</th>
<th>Fuel (Mg/ha)</th>
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</thead>
<tbody>
<tr>
<td>Iris-8</td>
<td>Pine saplings: 4, Palms: 3, Shrubs: 2, Ground layer: 11</td>
</tr>
<tr>
<td>Orchid-8</td>
<td>Pine saplings: 5, Palms: 4, Shrubs: 2, Ground layer: 9</td>
</tr>
<tr>
<td>Dogwood-11</td>
<td>Pine saplings: 6, Palms: 5, Shrubs: 2, Ground layer: 8</td>
</tr>
<tr>
<td>Poisonwood-12</td>
<td>Pine saplings: 7, Palms: 6, Shrubs: 4, Ground layer: 5</td>
</tr>
<tr>
<td>Iris-14</td>
<td>Pine saplings: 8, Palms: 7, Shrubs: 6, Ground layer: 5</td>
</tr>
<tr>
<td>Locustberry-14</td>
<td>Pine saplings: 9, Palms: 8, Shrubs: 4, Ground layer: 4</td>
</tr>
<tr>
<td>Buttonwood-30</td>
<td>Pine saplings: 10, Palms: 9, Shrubs: 5, Ground layer: 4</td>
</tr>
</tbody>
</table>
Path diagram showing the relationships among fuel types, fire intensity and fuel consumption.

(The thickness of lines indicates relative strength of significant correlations)

Sah et al. (2006)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Direct</th>
<th>Indirect</th>
<th>Total</th>
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<tbody>
<tr>
<td>Ground fuel</td>
<td>0.32</td>
<td>0.05</td>
<td>0.38</td>
</tr>
<tr>
<td>Palm fuel</td>
<td>0.11</td>
<td>0.15</td>
<td>0.26</td>
</tr>
<tr>
<td>HW shrub fuel</td>
<td>-0.29</td>
<td>0.02</td>
<td>-0.27</td>
</tr>
<tr>
<td>Char height</td>
<td>0.27</td>
<td>Not modeled</td>
<td>0.27</td>
</tr>
<tr>
<td>Season</td>
<td>0.05</td>
<td>0.14</td>
<td>0.19</td>
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</table>
HW shrub fuel vs Ground fuel consumption

Season and fire severity

- Ground fuel consumption (%) vs Pre-burn hardwood shrub fuel (Mg/ha)
- Char height (m) vs Pre-burn hardwood shrub fuel (Mg/ha)

Season and fire severity:
- Summer
- Winter

Plots:
- Orchid (1998)
- Poisonwood (1998)

R² = 0.15
P < 0.001
Site - Poisonwood

Char height

Summer burn

Scorch %

Winter burn

Trees survived

Trees killed by fire

Char height (m)
- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 6
- 6 - 7
- 7 - 8
- 8 - 9
- 9 - 10
- >10

Scorch %
- 0 - 20
- 20 - 40
- 40 - 60
- 60 - 80
- 80 - 100

Tree DBH class
- 5 - 10
- 10 - 15
- 15 - 20
- 20 - 25
- 25 - 30
- >30
Tree size, fire severity & pine tree mortality
Tree size, char height & pine tree mortality

$$P(m) = \frac{1}{1 + e^{-(1.22 - 0.20*DBH + 0.90*CharHt)}}$$

<table>
<thead>
<tr>
<th>DBH (cm)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>&gt;10</th>
</tr>
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<tbody>
<tr>
<td>5-10</td>
<td>0.112</td>
<td>0.212</td>
<td>0.386</td>
<td>0.632</td>
<td>0.838</td>
<td>0.921</td>
<td>0.968</td>
<td>0.982</td>
<td>0.995</td>
<td>0.998</td>
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<tr>
<td>10-15</td>
<td>0.047</td>
<td>0.095</td>
<td>0.203</td>
<td>0.397</td>
<td>0.612</td>
<td>0.807</td>
<td>0.915</td>
<td>0.969</td>
<td>0.986</td>
<td>0.994</td>
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<tr>
<td>15-20</td>
<td>0.018</td>
<td>0.038</td>
<td>0.094</td>
<td>0.212</td>
<td>0.411</td>
<td>0.629</td>
<td>0.820</td>
<td>0.891</td>
<td>0.957</td>
<td>0.988</td>
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<tr>
<td>20-25</td>
<td>0.005</td>
<td>0.016</td>
<td>0.036</td>
<td>0.086</td>
<td>0.193</td>
<td>0.424</td>
<td>0.591</td>
<td>0.795</td>
<td>0.935</td>
<td>0.963</td>
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<tr>
<td>25-30</td>
<td>0.002</td>
<td>0.006</td>
<td>0.015</td>
<td>0.039</td>
<td>0.100</td>
<td>0.206</td>
<td>0.441</td>
<td>0.641</td>
<td>0.727</td>
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<tr>
<td>&gt;30</td>
<td>0.001</td>
<td>0.003</td>
<td>0.005</td>
<td>0.010</td>
<td>0.031</td>
<td>0.058</td>
<td>0.254</td>
<td>0.367</td>
<td>0.588</td>
<td>0.779</td>
</tr>
</tbody>
</table>
Mean ground elevation vs fire and storm surge (2005) induced cumulative pine tree mortality

Tree mortality (%) vs Plot mean ground elevation (m)

- Burned
- Unburned

Equations:
- Mortality = 46.1 * Elev^{-0.45}, R^2 = 0.411
- Mortality = 135.2 * Elev^{-0.727}, R^2 = 0.926
Logistic model – tree mortality in relation to dbh
Stand structure in BPK Pine forest

Change in stand density index (SDI)

SDI (≥5 cm; 2008) = 5 to 255

Change in average stand diameter (cm)

MSD (2008) = 9.1 to 17.2 cm
Conclusions

- Fire intensity increased with surface fuel loads, but was negatively related to the quantity of hardwood shrub fuels. probably because these fuels are associated with a moist microenvironment within hardwood patches, and therefore tend to resist fire.

- Winter fires were milder than summer fires, however effects of season on tree mortality varied among sites.

- Fire-induced mortality was higher in small tree classes, whereas storm surge effects were concentrated on large trees.

- The stand structure pine forests in Big Pine Key has changed quantitatively over the decade, primarily due to effects of both fire and storm surge-caused tree mortality.
Acknowledgements

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