Trees in Ice Storms: Developing Storm Resistant Urban Tree Populations

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“The ice-storm! the ice-storm! … and even the laziest sleepers throw off the covers and join the rush for the windows.”

From Following the Equator by Mark Twain, 1897
The Not So Beauty of Ice Storms

Damaged Vehicles
Structural Damage
Destroyed Trees

What is the worst that can happen

1) Tree Damage is Possible
2) Response Needs Coordination
3) Recovery Takes Time
4) Prepare Now for Storms

Trees and Ice Storms ... Like a Three Act Play

Act I: Ice Storms in the Urban Forest

Act II: Why Do Trees Fail from Ice Storms

Act III: Prevention and Management

Act One:
*Weather, Storms and the Urban Forest*

- Many Storm Types
  - Floods
  - Moisture Stress/Drought
  - Ice Storms
  - Tornadoes
  - Lightening
  - Hurricanes
  - Nor’easter
  - Straight-line Winds
  - Forest Fires

- When and how often?
In Severe Ice Storms

Transmission Towers Topple

Trees, Ice Storms, and Power Lines

Significance of Ice Storms: Safety, Property Damage, and Economic Hardship!

Monetary Losses from Ice Storms

- 60% of winter storm losses
- $16.3 billion property losses (1949 – 2000)
  - Mean annual cost $226 million
  - Insured losses only 87 ice storms
- 1998 NE United States and SE Canada
  - Estimated $6.2 billion
  - Four million people without power
  - Over 40 deaths attributed to the ice storm

1990 Ice Storm in Urbana Illinois

One million dollars damage
Parkway trees only

1991 Rochester, NY $40 million

<table>
<thead>
<tr>
<th>Tree Species</th>
<th>Removed</th>
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<tbody>
<tr>
<td>Norway maple</td>
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Total: 292,785

*Values are approximate and may vary due to rounding.

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December 2007 Ice Storm

- Regional Storm
- Approximately 20 deaths
- 800,000 without power

Ice Storm Frequency and Formation

- Occur annually within North America
- Extreme regional storms 10 to 20 years
- Return interval 20 to 100 years
- An important forest disturbance factor
- ¼ inch or more of ice accumulation
- Warm front passing over cold front

How do Ice Storms Form?

Most commonly warm front advances over cold front

How Common are Ice Storms?

Ice Accumulations:
10 to 100 times Branch Weight
Trees … Primary cause of outages

Early Documented Ice Storm Account

- Von Schrenk (1900) described
- Damage Potential of ice storms on trees
- Area covered over 5,000 square miles (Missouri, Illinois, Indiana, and Ohio)
- Damage exacerbated by
  - ice accumulation
  - strong winds


Ice Loading Factors

- Storm duration and intensity
- Geographical location (slope, aspect, elevation)
- Wind
- Tree attributes (species, architecture, physical properties, defects, and size)
- Spatial scale of storm
- Forest stand density

Trees in Ice Storms: Developing Ice Storm Resistant Urban Tree Populations

Act II

Why do trees fail from ice storms

Why do Trees Fail During Ice Storms?

- Is it Because Trees are Weak Wooded?
- Wood strength of sound branches
  - less important than
  - ability to withstand breakage
- Tree failure cause
  - ice accumulation
  - exceeds the capacity to hold

Wood Strength Properties

1) Specific Gravity
2) Modulus of Rupture
3) Modulus of Elasticity

No Relationship with Tree Damage

Compare Honeylocust to Arborvitae
**Preexisting Conditions**
Wounds and Decay

**Why did this tree fail?**
Decay

**Why did this tree fail?**
Dead

**Potential for Failure**

**Resistance Features**
- Small stature trees
- Excurrent form
- Favorable branch attachment
- Flexibility
- Coarse branching
- Protected site

**Susceptibility Features**
- Dead branch
- Broken branch
- Decay
- Included branch
- Fine branching
- Shallow rooting habit
- Exposed site
Root Damage

Rooting Profile and Tipping

- Shallow root systems more prone
- Deep-rooted species less prone
- Wet soils exacerbate problem

Sudden tree failure(s) from SGR’s during wind storm

Residual Damage

Edge Trees

Branch Shedding
Trees in Ice Storms: Developing Storm Resistant Urban Tree Populations

Act III
Prevention and Management

Table 1. Ice Storm Susceptibility of Tree Species Commonly Planted in Urban Areas

<table>
<thead>
<tr>
<th>Susceptible</th>
<th>Intermediate resistance</th>
<th>Resistant</th>
</tr>
</thead>
<tbody>
<tr>
<td>American elm</td>
<td>Bur oak</td>
<td>American sweetgum</td>
</tr>
<tr>
<td>American linden</td>
<td>Eastern redbud</td>
<td>Black alder</td>
</tr>
<tr>
<td>Black cherry</td>
<td>Red maple</td>
<td>Black cherry</td>
</tr>
<tr>
<td>Bradford pear</td>
<td>Sugar maple</td>
<td>Sugar maple</td>
</tr>
<tr>
<td>Cottonwood</td>
<td>Star magnolia</td>
<td>Cottonwood</td>
</tr>
<tr>
<td>Green ash</td>
<td>Swamp willow</td>
<td>Eastern hemlock</td>
</tr>
<tr>
<td>Honey locust</td>
<td>Swamp white oak</td>
<td>Swamp white oak</td>
</tr>
<tr>
<td>Pin oak</td>
<td>Siberian elm</td>
<td>Siberian elm</td>
</tr>
<tr>
<td>Silver maple</td>
<td>White ash</td>
<td></td>
</tr>
</tbody>
</table>

Adapted from Hauer et al. (1992).

Siberian Elm – the poster child of ice storm susceptibility

Tree Architecture

Bradford Callery pear, a weak-structured cultivar
Antechinus Callery pear, a stronger-structured cultivar
Image by Edward F. Gilman (1967)
Recovery from Ice Storms can be Slow
Leaving it alone can be hard
Removing ice can cause more damage
Residual Damage Can Last Several Years
Snaps for Ice Storms
Cracks Can Appear Months or Years Later
Repair Often Creates Problems Later
Bio …. Logical in the Urban Forest

How to Develop Ice Storm Resistant Tree Populations

1. Minimize the abundance of susceptible species (i.e., diversity)
2. Regular and proper tree maintenance
3. Remove included branches
4. Small trees and power lines are compatible
5. Develop disaster recovery plans before the disaster occurs

Model to Predict Proportion of Damaged Trees [Lafon 2004]

\[ y = -0.0696 + 0.0154x, \]
\[ y = \text{proportion of trees damaged} \]
\[ x = \text{ice thickness (mm)} \]

- Typical ice storm (Changnon 2003)
  - 1 cm (0.4 in) of ice thickness
  - 10% or fewer trees damaged
- Our study sites (Hauer et al. 2011 in review)
  - 36 mm (1.4 in) ice thickness
  - approximately half of the trees would be damaged

Models to Predict Ice Storm Debris [Hauer et al. 2010 & 2011]

**Model 1: Includes Large Community, Large Storm**
\[ R^2_{adj} = 0.949 \]
\[ \text{Debris volume (yds}^3\text{)} = -129,677 + 655.1 \times \text{street distance (mi)} + 49,426.5 \times \text{ice thickness (in)} \]

**Model 2: Excludes Large Community, Large Storm**
\[ R^2_{adj} = 0.792 \]
\[ \text{Debris volume (yds}^3\text{)} = -82,529 + 5,314.4 \times \text{land area (mi)} + 41,651.5 \times \text{ice thickness (in)} \]

Approximation of Debris

<table>
<thead>
<tr>
<th>Approach</th>
<th>N</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Error of Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Street Mile (yd/mi/in)</td>
<td>37</td>
<td>17.61</td>
<td>13,600.0</td>
<td>2,531.14</td>
<td>508.89</td>
<td>3,095.44</td>
</tr>
<tr>
<td>Land Area (yd/mi/in)</td>
<td>36</td>
<td>3.29</td>
<td>1,114.8</td>
<td>247.12</td>
<td>49.01</td>
<td>294.05</td>
</tr>
</tbody>
</table>

**Figure 1b.** Actual reported and predicted tree debris volumes with 95% confidence intervals from model one (street distance and ice thickness) for 39 communities.

**Table 5b.** Estimation of tree debris following an ice storm (full and final models w/o Springfield, MO and St. Louis, MO; English Units).

<table>
<thead>
<tr>
<th>Model Variables*</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>t-test Statistics</th>
<th>Correlations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-1740238</td>
<td>77189.338</td>
<td>-2.254</td>
<td>.032</td>
</tr>
<tr>
<td>Street Distance (mi)</td>
<td>657.033</td>
<td>26.762</td>
<td>24.55</td>
<td>.000</td>
</tr>
<tr>
<td>Ice Thickness (in)</td>
<td>5207.4</td>
<td>1609.733</td>
<td>3.267</td>
<td>.000</td>
</tr>
<tr>
<td>Max. wind speed (mph)</td>
<td>67.778</td>
<td>2850.931</td>
<td>-0.001</td>
<td>.981</td>
</tr>
<tr>
<td>Canopy Cover (%)</td>
<td>2160.826</td>
<td>1675.791</td>
<td>1.289</td>
<td>.207</td>
</tr>
</tbody>
</table>

**Final a priori Model**
\[ (R^2 = 0.952, R^2_{adj} = 0.949, \text{std. error of est.} = 108324, \{(1,13)\} = 226.8, \text{p} = .000) \]

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<th>t-test Statistics</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-129677</td>
<td>3076.134</td>
<td>-4.219</td>
<td>.001</td>
</tr>
<tr>
<td>Street Distance (mi)</td>
<td>655.146</td>
<td>25.627</td>
<td>25.57</td>
<td>.000</td>
</tr>
<tr>
<td>Ice Thickness (in)</td>
<td>4942.87</td>
<td>15546.422</td>
<td>3.221</td>
<td>.000</td>
</tr>
</tbody>
</table>
### Table 6b. Estimation of tree debris following an ice storm (full and final models without Springfield, MO, St. Louis, MO and Tulsa, OK, English Units).

<table>
<thead>
<tr>
<th>Model Variables*</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>t-value</th>
<th>Sig.</th>
<th>Correlations</th>
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<tbody>
<tr>
<td><strong>Initial Model: All Indicators</strong> ($R^2 = .808$, $R_{adj}^2 = .782$, std. error of est. = 788824, $F(4,29) = 30.594$, $p &lt; .000$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>(Intercept)</td>
<td>-70900.0</td>
<td>53680.0</td>
<td>-1.414</td>
<td>.168</td>
<td></td>
</tr>
<tr>
<td>Street Distance (mi)</td>
<td>5139.2</td>
<td>529.298</td>
<td>.844</td>
<td>9.709</td>
<td>.000</td>
</tr>
<tr>
<td>Ice Thickness (in)</td>
<td>44766.580</td>
<td>11758.997</td>
<td>.321</td>
<td>3.807</td>
<td>.001</td>
</tr>
<tr>
<td>Max. wind speed (mph)</td>
<td>-1117.889</td>
<td>2015.375</td>
<td>-0.048</td>
<td>-0.555</td>
<td>.583</td>
</tr>
<tr>
<td>Canopy Cover (%)</td>
<td>821.462</td>
<td>1210.897</td>
<td>.061</td>
<td>.678</td>
<td>.503</td>
</tr>
<tr>
<td><strong>Final a priori Model</strong> ($R^2 = .797$, $R_{adj}^2 = .784$, std. error of est. = 76284, $F(2,33) = 64.657$, $p &lt; .000$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>(Intercept)</td>
<td>-82529.4</td>
<td>23280.564</td>
<td>-3.545</td>
<td>.001</td>
<td></td>
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<tr>
<td>Land Area (km²)</td>
<td>5314.390</td>
<td>480.733</td>
<td>.873</td>
<td>11.055</td>
<td>.000</td>
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<tr>
<td>Ice Thickness (cm)</td>
<td>41651.486</td>
<td>10740.973</td>
<td>.306</td>
<td>3.871</td>
<td>.000</td>
</tr>
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**Figure 2b**. Actual reported and predicted tree debris volumes with 95% confidence intervals from model two (land area distance and ice thickness) for 39 communities.

**Figure 8b.** Prediction of tree debris volumes for the mean community size (land area = 28.7 mi², street distance = 375 mi, and population = 55,750 people) from this study with upper and lower 95% confidence intervals, English Units.

### Ice Storms Happen

- Tree failure is predictable
- Trees vary in susceptibility
- Take steps before hand