Tree Sway in Northern Deciduous Forests

Understanding Tree Responses to Wind Exposure Along our Wooded Roadsides

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The Situation

In the Northeast, people live in proximity to trees.

-Southern New England has the 4th, 5th and 6th most densely populated states
-Forest covers 54-64% of states area
-65% of Connecticut is considered Wildland-Urban Interface (7)

Benefits of Trees in Connecticut:

- 23.3 million metric tons of carbon sequestered (valued at $531.2 million) (7)
- Adding 767,000 metric tons of C per year (7)
- 17,380 metric tons of air pollution removed per year (valued at $145.1 million) (7)
- A forested watershed can do the water purification work of a multi-billion dollar treatment plant.
- Shade and shelter reduce household heating and cooling costs (1)
- The presence of trees has been shown to increase property values, reduce traffic speed, improve worker productiveness and improve consumer enthusiasm (1)
- Reduction of noise pollution, soil erosion and flood risk (1)
- Habitat for wildlife and biodiversity that is not supported in an otherwise urban environment (1)
- Hiking, camping, hunting, birding, Maple sugaring, etc.

However...

-Southern New England forest is highly fragmented and under stress
-49% of forested land is within 300 ft. of development or agriculture
-Storm regimes in the Northeast appear to be increasing in frequency and severity

Trees are the most common threat to utility lines

Trees have been estimated to cause up to 90% of power outages in storms in Southern New England. Eversource Energy has allocated $75 million for tree trimming in just CT in 2017, with an additional $10 million from state and local government (2).

Power lines and trees knocked down by Superstorm Sandy on Davis Hill Road in Weston, CT. Photo by Sgt. Mike Fergus, November 8, 2012. https://internationalmedicalcorps.org

What can we do to mitigate danger to utility infrastructure, While protecting trees and their many benefits?

Study Objectives

To better mitigate the threat to utilities, while protecting the northeast urban forest, we need to better understand the response of trees to wind, and how forest management can effect that relationship.

The objective of this study is to identify driving factors of **tree sway frequency** from characteristics of:

1) Environmental conditions (Wind, temperature and foliage condition)
2) Tree architecture
3) Forest stand structure

In previous tree sway studies, DBH/(height^2) has been predictive of frequency in coniferous trees.

Variables Describing the tree **crown** have been found to be predictive of frequency for deciduous broad-leafed trees.

Parameters under investigation

Environmental Conditions:
- Foliage on or off
- Freezing temperatures above or below
- Maximum wind speed
- Median wind speed
- Time of Day
- Standard Deviation of Wind speed
- Maximum wind speed divided by average speed

Environmental conditions + Forest Structure
- Shelter
- Support

Tree Architecture
- Height
- DBH (Diameter at 14m)
- Slenderness: DBH/(height^2), DBH*height, or change in diameter per m
- Youngs' Modulus of elasticity (Species-specific parameter)
- Species
- A parameter describing the tree as a cantilever beam (3)
- Height from ground to base of live crown
- Height from base of live crown to tree top
- Percentage of total tree height that is live crown
- Crown radius
- Crown volume
- Crown closure
- Symmetry

Surrounding Forest Structure
- Basal area
- Stems per hectare
- Site: catch-all variable for variations between the three sites

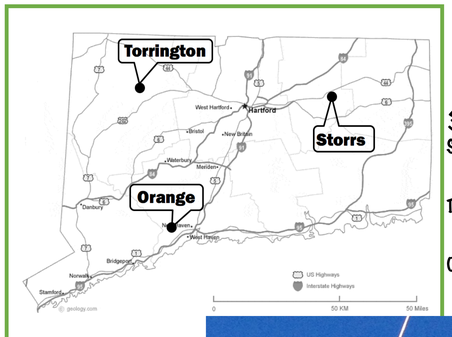
Trees respond to wind in two ways:

Immediate kinetic response
Tree Sway
A repeating periodic motion that can be described by
Frequency: How fast it goes back and forth
And **amplitude:** How far a tree gets from it's resting position.

Long-term developmental response
Thigmomorphogenesis
Variation in tree development due to mechanical stimuli such as **wind.**
Trees exposed to more wind develop a more stout shape, bushier branching structure, and allocate more resources to root growth for anchorage

Materials and Methodology

We Monitored the sway of 41 trees in three roadside sites in Connecticut for one year, and simultaneous environmental conditions. Following that, we regressed frequency-of-sway on parameters of the wind and temperature, and of the architecture of the tree and surrounding forest.



3 roadside study sites in Connecticut

Storrs: 0.18 hectares, 183m ASL., Sandy loam soils, very stony Black birch, Hickory, Maple, Oak, 40.4 m2/ha basal area, 504 stems/ha

Torrington: 0.3 hectares, 366m ASL, Sandy loam soils, extremely stony, Maple, White ash, White pine, 39 m2/ha basal area, 1153 stems/ha

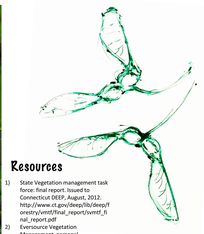
Orange: 0.7 hectares, 61m ASL, Wetland soils, flood prone Maple, Oak, Black tupelo, Yellow poplar, 39 m2/ha basal area, 432 stems/ha

Meteorological Tower
Set up to canopy height in a nearby clear area
Tracking wind speed and direction
(R.M. Young Wind Monitor, Campbell Science)
As well as ambient temperature

41 trees monitored for one year
9 species:
Red maple
Sugar maple
Pignut Hickory
Shagbark hickory
Black birch
Yellow poplar
Black tupelo
White pine
Red oak
Height range:
8-32m (average = 21m)
Diameter range:
12-68cm (avg. = 32cm)

Biaxial Inclinometers
1 for each tree
Continuously track angle of bending in two directions.
(A-900 model; Jewell Instruments)

Biaxial inclinometer in weather-proof housing Fixed to a maple in the Torrington site



Resources
1) State Vegetation management task force: final report. Issued to Connecticut DEEP, August, 2012. http://www.ct.gov/deep/lib/deep/forestry/uvmtf/final_report/uvmtf_final_report.pdf
2) Eversource Vegetation Management, personal communication via John Volin. 2016.
3) AASHTO, LTS. "Standard Specifications for Structural Supports for Highway Signs." *Luminaires and Traffic Signals* (2013).
4) Baker, C. J. "The development of a theoretical model for the wind throw of plants." *Journal of Theoretical Biology* 175.3 (1995): 355-372.
5) Kane, Brian, et al. "Effects of crown structure on the sway characteristics of large decurrent trees." *Trees* 28.1 (2014): 151-159.
6) Harja, Degi, et al. "Tree shape plasticity in relation to crown exposure." *Trees* 26.4 (2012): 1275-1285.
7) Nowak, David J., and Eric J. Greenfield. "Urban and community forests of New England: Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont." (2008).

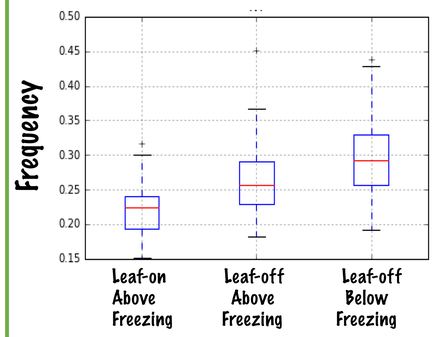
Results

Final model for predicting tree sway frequency:

$$FVF = INT + \beta_1(Condition) + \beta_2(DBH/H^2)$$

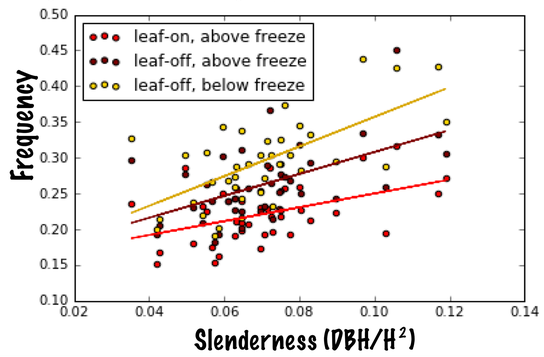
Condition Parameter

3-level categorical variable. Foliage and freezing temperatures effect Frequency, so must be accounted for in a predictive model.



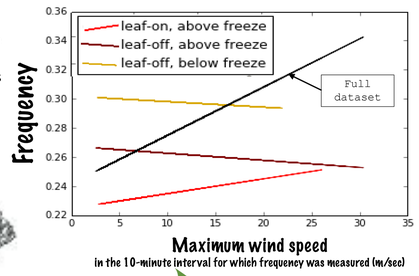
Slenderness (DBH / H^2)

This measurement of slenderness is the best predictor of frequency for an individual tree. Several other parameters that also showed potential as predictors were no longer significant in a model containing this parameter.



Wind speed

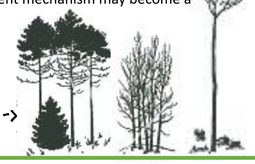
As expected, wind speed did not contribute to the prediction of frequency. Certain times of the year have higher wind speeds and also particular weather conditions.Thus, wind speed is correlated with the condition parameter. In a plot of wind speed versus frequency, a distinct positive correlation is evident. However, if the data are broken out into the 3 conditions, that correlation is nullified. The relationship is no longer evident. Wind speed was only a proxy for the more effective condition parameter.



Crown Parameters

Previous studies have found measurements of the crown to be predictive of sway frequency for deciduous broad-leaved trees (5). This was not the case in our study. This could be because previous studies used open-grown trees, whereas our forest-grown trees more closely resemble the shape of previously studied coniferous trees This may suggest that tree shape is the dominant frequency predictor, or that there is some thresh-hold of shape where a different mechanism may become a stronger predictor of frequency.

Tree Shape:
<- Open-grown
Forest-grown ->



Conclusions

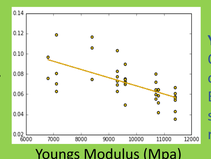
Frequency of trees in the Southern New England roadside forest, temperate deciduous mixed and mostly even aged stands, is driven primarily by tree **slenderness defined as DBH/H^2.**

What's Next?

What frequency do we want to encourage?
Studies have suggested that a tree with a higher frequency is more wind-firm (4).
Such a tree would have developed features (due to thigmomorphogenesis) that make it resistant to damage or overturning in a storm event.

How can we manipulate frequency?
This study found that DBH:height ratio (slenderness) is correlated to frequency, with positive trend, suggesting a tree with a higher DBH:H ratio would have a higher frequency. So, can we manage for these more stout trees? Sure! The ratio is related to many things foresters or arborists manage in woodlots.

More Stout
DBH/H^2
More Slender



Youngs modulus of elasticity (Mpa)
Our data suggests a correlation of elasticity with slenderness. Elasticity is species specific. Further study of the species/slenderness relationship is necessary.

Stand Density
Stand density has often been found to have a greater effect on DBH than on tree height and is thusly an influence on slenderness (6).

Exposure to direct sunlight
Harja et al. (6) found trees to become more slender when they were shaded, as opposed to trees with some or full overhead sunlight.

Future Research Questions :

- What are the drivers of displacement, a.k.a amplitude of sway?
- What changes of sway frequency and amplitude occur in forest stand thinned to allow remaining trees to experience a greater wind regime, and develop accordingly?
- What amount of feature development is possible for a mature forest tree?
- What sort of time frame would these developments take place in?

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