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The Wind in the Woods: A short report on Tree Biomechanics

My name is Amanda Bunce. I'm a graduate student at UCONN in the Natural Resources dept.
I study tree biomechanics and tree/wind interaction

I work with the Eversource Energy Center on a project called Stormwise,
Where we have many researchers looking at management of urban forest to lessen the incidence of Tree-powerline interaction during storms.

We have people working on mapping of forests and utilities
Value recovery for wood products
Making demonstration sites
Investigating the social science aspect
And we look at biomechanics of trees, primarily their interaction with the wind. That's me.

My tree biomechanics project investigates tree sway in SNE roadside forest

Connecticut has a dense population and a lot of tree cover.
So, we have a great amount of wildland-urban interface here (65% of area in CT, the most %)

Maine, in contrast, they have like 20%
For the most part, people and trees live far apart there

Forest borders many of our roads, forming these picturesque "green tunnels"

And aesthetics and shade aren't the only benefit to living amongst trees, like we do.
Carbon sequestration, cleaner air, water filtration, wildlife habitat, recreation, etc.

However, trees are the biggest threat to utility lines in storms, esspecially in SNE

So, In a broad sense we are asking "Can we manage the forest to mitigate that threat?

While we conserve forest and all of its eco-functionality and benefits?"

So today I'm sharing with you something I've had to learn a lot about over the course of this project:
Tree and Wind Interaction.

A tree has two fundamental reactions to the wind:

1. Their immediate kinetic response, to wind force, or wind loading. That would be the swaying they do.
2. And their long-term adaptive and developmental responses to that force, its regular occurrence
   a.k.a. the wind regime. That response is called thigmomorphogenesis. We'll get back to it.

1: The kinetic reaction to wind

The wind is a force pushing on the tree, like you or me pushing a kid on a swing
That force is energy, and the laws of physics say it has to go somewhere.
the law of the conservation of energy says that energy can be neither created nor destroyed

Energy can transform from one kind of energy to another

Like chemical to heat in an explosion

But here we're talking about transference of energy like one of these newtons devices

swing a ball and the kinetic energy is transferred to the last ball

The force of the wind is transferred to the tree

And the tree is set in motion. It begins to sway.

Sway is a periodic motion that can be described by a frequency and an amplitude
Frequency is how fast it sways. How long it takes to complete one back-and-forth motion.
Amplitude is how far it bends. The distance it gets from the resting point.

With regards to sway, we're also going to touch on MOTION DAMPING which is the tree sway coming to a stop, and STREAMLINING, which is a mechanism for avoiding the wind force to begin with.
Some trees are more effective at one of these or another. Frank Telewski called them "wind-tolerators" and "wind-avoiders".

Now, eventually, movement ceases.
Even those executive ball clickers don't swing forever…
The energy is dissipated by transferal or transformation and ultimately leaves the tree.
The loss of the energy is called motion damping.
Trees employ the elastic quality of wood to move and return to still without permanent damage
R. Milne, in the 90's, determined t e 3 major ways that trees damp motion.
in Crown Clashing, or collisions with other trees (50% is done here)
This transfers motion just like the ball clickers to neighboring trees
Spreading the energy out and eventually it is lost in the friction of the encounters
In friction with the air, called aerodynamic damping (40%)
Everytime an aspen leaf trembles it's losing some of it's energy as heat in friction
With the air
in "viscous damping" (10%)
internal. loss of energy as heat via the elastic motions of the tree
from the friction between the trees own rigid cells,
and the energy used to deform them

Streamlining is a method of avoiding the force of the wind in the first place.
Some trees have leaves that deform in high wind, making them more aerodynamic and letting more of the wind force go by unhindered
Some trees streamline by reshaping to a prevailing wind
They maintain less branching on the windward side.
These mechanisms are adaptations developed by the tree for survival
Because Swaying has risks…

Risk #1) Achieving an amplitude past your elastic capacity (obvious)
This is being pushed over by the wind. Being pushed beyond its elastic capacity to right itself

Risk #2) Resonance
Wind isn't a steady force. It pulses. It has a beat, a frequency.
The tree sways to a beat as well. Each tree has a unique frequency.
If those frequencies match, it increases amplitude exponentially!
Thats called "Resonance"
If you push a kid on a swing, if you do it right and you pus exactly as often as they swing back, you get more and more distance from each push

You see this in suspension bridges. They start to visibly undulate, the amplitude increases more

        - and more until it self destructs.
        - The wind pulses at the bridge with the same frequency that the bridge wants to swing.

    - This is a thing we do when trying to explain the concept to highschoolers, we try and achieve resonance by yanking a tree.
        - We yank a tree top with a rope, try to sync with the tree sway and achieve resonance!

    - Why does it look like we're having such a hard time?
    - Trees are actually adapted to avoid achieving resonance with wind
        - All tree parts (branches, twigs, leaves) sway with their own frequency, not the trunks'
            - like a small tuning fork would vibrate with a different freq. than a larger one.
        - They all have unique frequencies but they are all coupled together.
            - Each movement effects the movement of another
            - if they were tuning forks, they would be a cacophonous nightmare
            - The math determining the actual frequency of the trunk is complicated
                - to say the least.
        - As frequencies disrupt and counteract one another,
        - no coherent resonance can be achieved with the pulsing force of the wind.
        - Here is a model of an idealized tree. It turns out that higher order branches have higher frequencies and the trunk is always the lowest. The trunk sway frequency is normally the one we're talking about when we talk about tree sway.
- So to review:
- Trees sway as a result of transferred energy from the wind.
- They can avoid some of that energy by streamlining, or dissipate it with motion dampening
- They avoid resonance with the wind as a result of their branching structure

Which brings me to the second way trees remain standing in the force of the wind:
2: The long-term developmental response to the wind

- Overtime, a tree allocates resources in a manner that responds to its experience
- The growth response to **mechanical stimuli** is called "thigmomorphogenesis"
    - Coined by Jaffee in 1973 in is paper: …

- mechanical stimulations is wind, bending of the stems or consistent petting of the leaves by well-meaning scientists, or running over the leaves with rubber flaps
    - You can see in tis study that the plants that were physically messed with turned out physically different
    - This phenomenon is used in basil production because it encourages this short leafy stature

    - The developmental response of trees is generally in accordance with a particular wind regime
        - Jeffrey pines: One grown in a lesser wind condition
        - And one experiencing consistently stronger winds,
            - You can even see the prevailing wind direction in the streamlining

        - In SNE, young trees in a dense forest would be somewhat sheltered from wind
            - they would focus their resources on height for sunlight, and allocate less to stability.

        - Open grown trees, subjected to much greater wind much more often…
            - develop more elaborate root systems for anchorage

develop larger, more flared bases, improving their compressive buttressing ability
this is the mechanism by which huge gothic churches remain standing
Streamlining can occur in some species
a decrease in shoot elongation, accompanied by increase in girth creates a more tapered shape
Shorter internodes and branches give a tree a stout, bushy shape
Thicker branch nodes develop, due to constant bending stress
Shedding branches and growing smaller leaves are also streamlining techniques
Also less noticeable changes include
increased flexibility and density
Changes in cell structure and increased growth in areas of stress
compression and tension wood

In this study of constant flexing in pine saplings - resources were allocated away from height
And notice the needles are shorter and more densely packed
Study of Sweetgum trees, some guyed and some guyed and shaded
shading increased drive for light, guying decreases necessity for stability
some of the guyed and shaded ones didn't even develop the capacity to remain upright in absence of the stakes.

Now that we understand more about the dynamic interaction of wind and trees, how can we use this knowledge? Forest managers and arborists can benefit from taking into account these dynamic interactions:
Consider Planting
Consider species choices. What is the ultimate height? Thigmo can only shorten a tree so much.
Genetics are still in play here. A white pine can get to be 100 feet, even if open grown.
wood strength? Bradford pears snap in light winds.
Does this tree streamline? And does it do so by shedding?
Staking - Has its pros and cons.
Good staking provides a wide attachment point to the tree, allows for some movement, and is removed as soon as the tree begins to anchor itself
You don't want a tree like the sweetgums, lacking in capacity to stand.
And consider that a tree wants to increase in diameter as well. Girdling presents a stress, at least.
Pruning – There are proper pruning techniques and Certain amounts you can remove for tree health,
but also consider the fact that the tree uses the dynamic interaction of all it's branches to dampen sway
It's branch structure is adapted to its wind regime.
pruning should be done in small increments so the tree isn't stuck making some major changes
when a big windstorm comes along
Forest Management - This is sort of the big-picture idea
We can use our knowledge of how trees and winds interact to manage our forests to be wind firm
Species selection is important here too, And space to grow, move and adapt to moving
But not so much space that we take away another one of their motion damping mechanisms

There is no perfect tree or perfect way to grow a tree. Everything is a trade off. Every action has it's pros and cons. We can use all the knowledge we have to make sure we're balancing the pros and cons of management activities as best we can. The end. Questions?