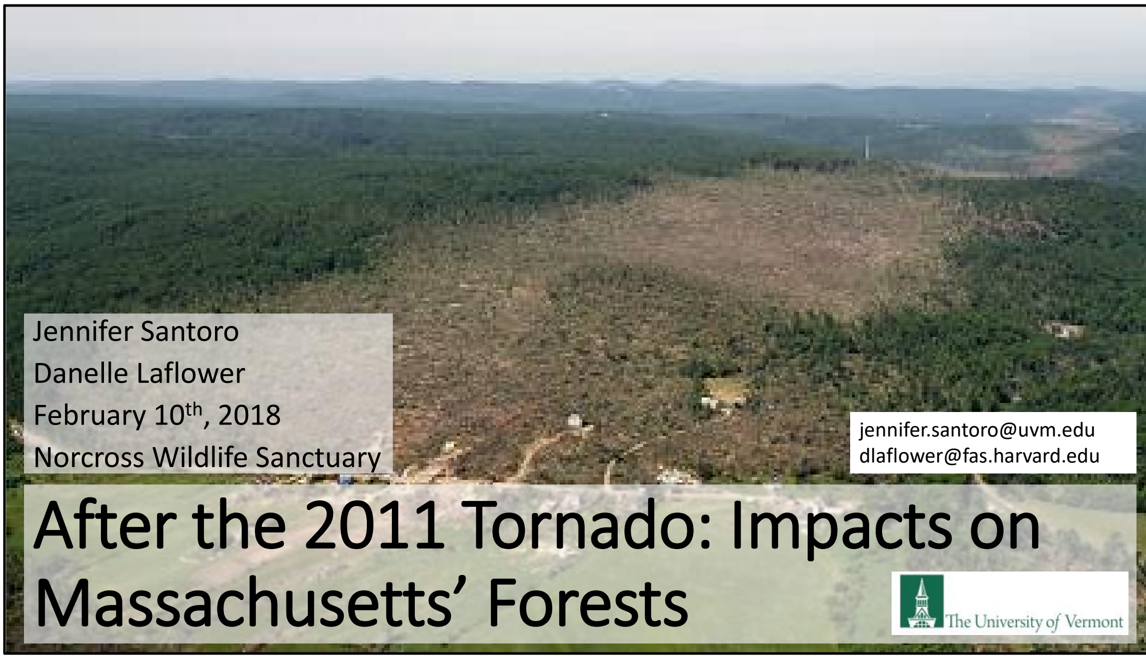

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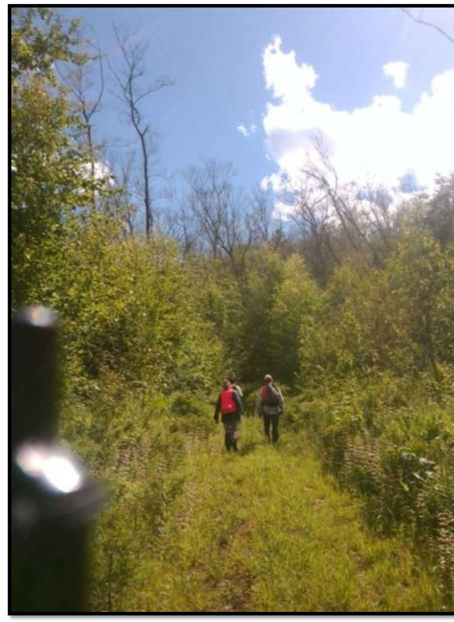
This talk was presented at the Norcross Wildlife Sanctuary on Saturday, February 10th, 2018. It will cover our research on forest regrowth 6 years after the 2011 tornado.

Presentation Outline

- **Forestry 101**
  - Stand development and structure
  - Natural disturbance
  - Salvage logging
- **Context of Our Study**
  - History of Brimfield State Forest
  - 2011 tornado
- **Research Objectives**
- **Field Work & Methods**
- **Findings & Results**
  - Overstory
  - Regeneration
  - Coarse Woody Debris (CWD)
- **Implications: What does this mean for the forest?**



Before we get into our research study, we will cover some “forestry 101” background on stand development and structure, natural disturbance, and salvage logging to set the stage for our research questions. Next, we will cover some background on the 2011 tornado and Brimfield State Forest before diving into our research project, results, and implications.

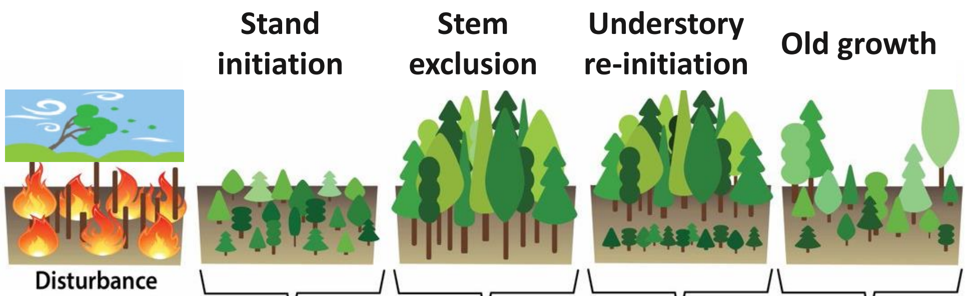
Forestry 101

Stand Development and Structure

Natural Disturbance

Salvage Logging

Stand Development Stages



Regeneration	Seeds, Seedbanks, AR	Resource limited	Gaps	Gaps
Mortality	Low	Density dependent	Density independent	Density independent

Time since disturbance →

When we think of forests, we often categorize them in a particular stage of development. Stage1, stand initiation, is instigated by disturbance. Species arrive through seeds, seed banks, and advanced regeneration. Light and other resources are generally ample.

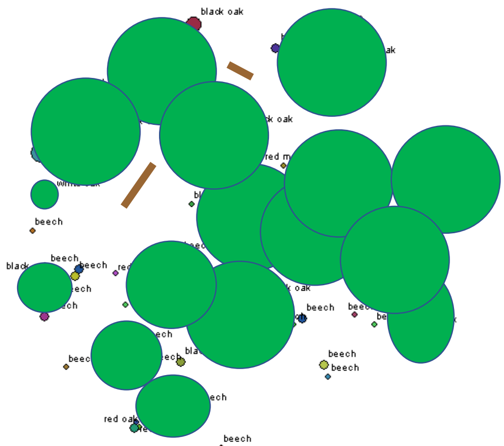
Stage 2, stem exclusion, begins at canopy closure. The canopy is too dense to allow regeneration, and mortality occurs due to resource limitation.

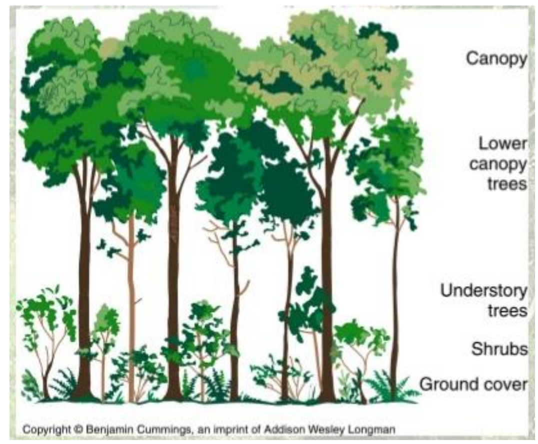
Stage 3, understory re-initiation begins when gaps created by mortality allow enough light to reach the canopy floor so reproduction begins again. Weather, pests, and old age cause mortality.

Stage 4, loosely called old growth, is a multi-aged forest. Gaps become larger and close more slowly. This stage contains trees of all size classes and a more complex structure.

Stand Structure

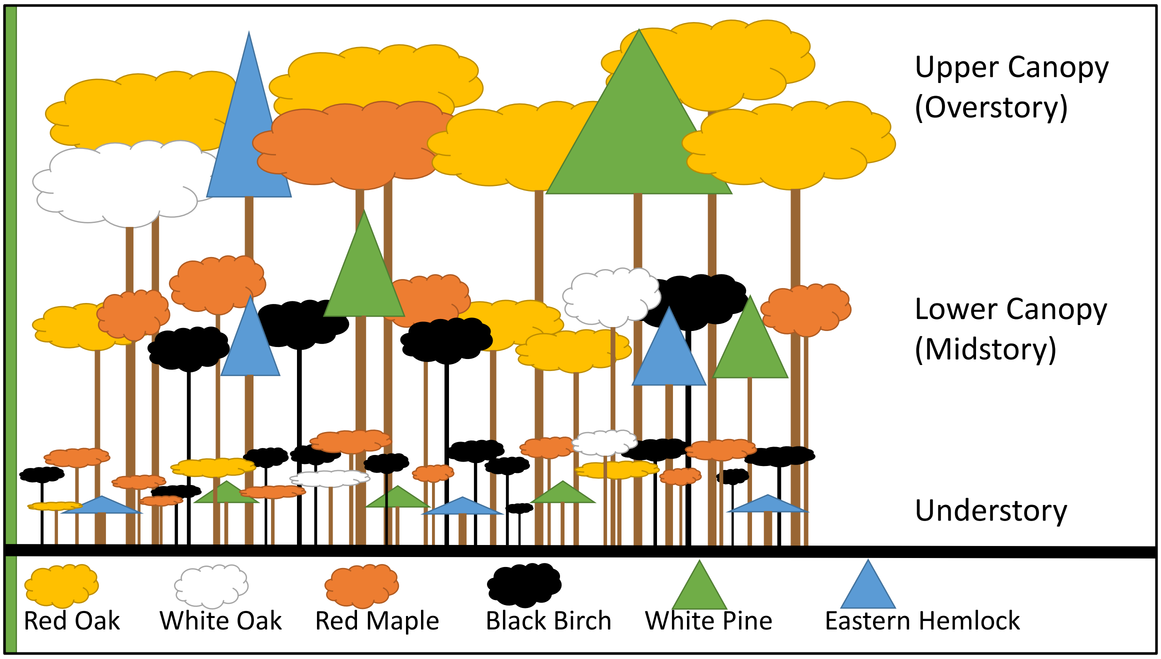
Horizontal and vertical distribution



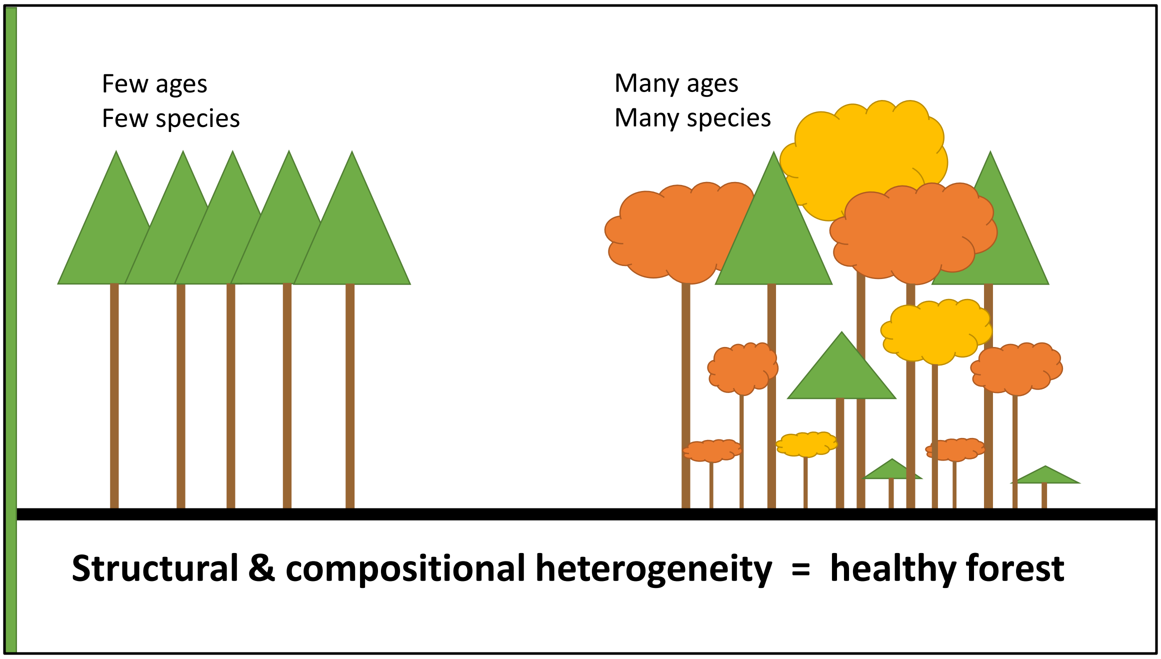


more structure = more variety = more habitat characteristics

So what do we mean by structure? It is the distribution of the physical parts of a forest, including: tree size/age, dead trees/wood, canopy, and vertical layers. More structure generally means more habitat characteristics. Understanding structure helps us interact with a forest and can shape our management decisions. *Structure is shaped by succession, disturbance, and harvest.*



Here's how a healthy forest structure might look in Massachusetts, with some of the common species found here. The upper canopy is dominated by red oak, with a mix of other common species such as white oak, red maple, white pine, and eastern hemlock. The lower canopy, or mid-story, has younger trees that will replace the canopy trees when they die. These include the same species, especially more shade-tolerant trees like red maple, black birch, and eastern hemlock. The understory layer is full of small seedlings and saplings (regeneration) that have seeded in from the mature trees. This structure has a diversity of sizes, ages, and species.



This diversity is very important for a healthy, resilient forest. However, forests can be very homogeneous too. This means there are few species and few age classes in the forest. A lot of plantations are structured like this, but they can be more susceptible to large natural disturbances, like insect outbreaks. Heterogeneous forests, on the other hand, have lots of diversity: many species, many ages, and many heights. Small trees in the understory replace large trees when they die, so the forest constantly regenerates itself. Often, natural disturbance helps to create this structure. This structural and compositional heterogeneity makes for a healthy, resilient forest. A lot of New England has forests that look like this.

Natural Disturbance

What is it?

- Discrete events that alter ecosystem dynamics
- Variable (intensity, frequency, severity, size)

The Bad

- Destructive
- Dangerous
- Costly

The Good

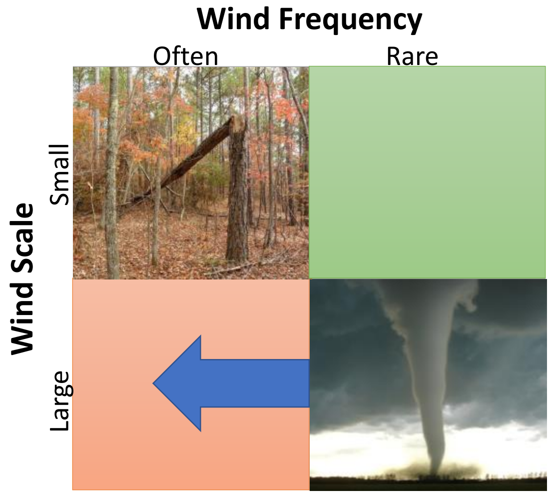
- Biodiversity
- Resilient ecosystems
- Wildlife habitat
- Structural & compositional heterogeneity

Let’s take a closer look at natural disturbance, since it plays such an important role in creating and maintaining healthy forests. Natural disturbance is any discrete event that changes an ecosystem. They can be small, like a single tree falling in a forest to create a gap, or large, like a tornado or the fires out west. Natural disturbances are variable in size, frequency, severity, and intensity. Usually, bigger, more severe disturbances occur infrequently. The common natural disturbance events that occur in a region is called a disturbance regime.

The word “disturbance” has a negative connotation, and there can certainly be bad things that come with natural disturbance. Large disturbances such as tornados or fire can be very destructive, dangerous, and costly. However, natural disturbances promote resilient ecosystems that can bounce back and can increase biodiversity. One main way disturbances increase biodiversity is by creating new, early-successional habitat. Many species, such as grouse and other bird species, live in this kind of habitat. Finally, since disturbance kills some parts of the forest, new trees can regrow, creating diversity in forest composition and structure.

Natural Disturbance Patterns in New England

- Dominated by small-scale wind events
- Projections for increasing frequency of large events
  - Rising sea surface & global temperatures
  - Shifting weather patterns
- **How will we handle this?**



We hear a lot about fires out west and hurricanes in the south. Here in New England, our natural disturbance regime is dominated by wind and insect outbreaks (like gypsy moth). Most often, these wind events are small and frequent, and only knock over a few trees. This is called gap disturbance because it just creates small gaps in the forest, where shorter trees can grow to fill in those gaps. However, sometimes (infrequently), we get large disturbances. Usually these are hurricanes and tornados.

Using climate models, scientists have predicted that there *may* be more large disturbance events in the future. This is based on models of rising sea surface temperatures and shifting weather patterns that aid in the formation of tornados and hurricanes in the Atlantic Ocean. So our large, rare tornado events *could* shift to large, more frequent tornado events. If this happens, we need to be prepared. How will we handle more tornados in New England? That’s where our research comes in.

This is a photo from the Civil Air Patrol, showing Hollow Road on the east side of Brimfield State Forest. While large natural disturbances have many benefits for the forest, no one would argue that more tornados is a positive thing, especially for people who live in close proximity to these natural areas. Tornados are destructive and costly, and despite some benefits to forests, an increased occurrence of tornados in this region would do a lot of harm.

Salvage Logging

What is it?
- Removing fallen trees
- Response to large disturbance events

The Good
- Reduce hazards (safety)
- Recover value
- Aesthetics

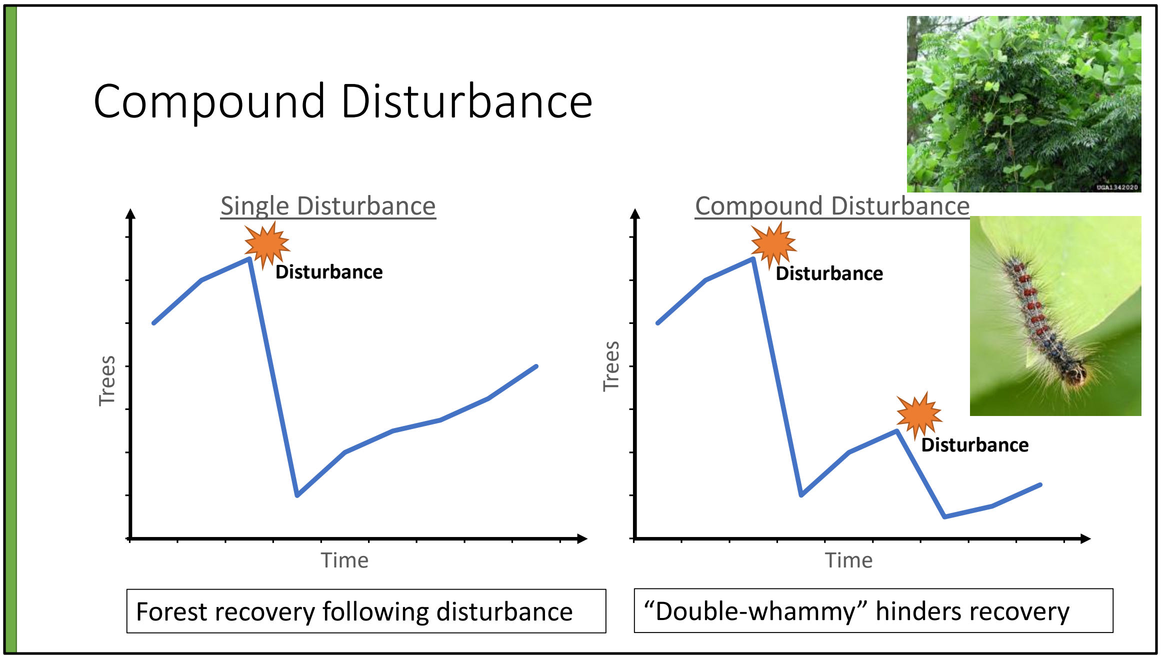
The Bad
- Compound disturbance
- Potential cumulative impacts

There may be more salvage logging in the future if we experience more large disturbances




A common response to large wind-cased natural disturbances is salvage logging. This practice involves removing the fallen trees from the ground soon after the disturbance event occurs. Salvage logging is a common practice throughout the US, and there are many good reasons for doing it. First, salvage logging can reduce hazards and create a safer environment for people. Tons of dead wood on the ground increases fire risk, so it is wise to mitigate that risk. Additionally, salvage logging can help to recover some value from a forest. Often, the recovered value is small because the wind can break and twist trees, lowering their merchantability. Finally, many salvage logging operations take aesthetics into account when cleaning up an area.

However, there are also some negative impacts that *could* arise from salvage logging practices. Because it tends to occur right after a large natural disturbance, salvage logging could cause a compound disturbance, or a second disturbance immediately after the first. I like to think of this as being home sick with the flu. Then one cold day, you walk outside to get your mail, and you slip and fall on the ice. Now you've been hurt twice - compound disturbance! There could be potential cumulative impacts to getting hit with two disturbances in a row. I'd like to emphasize that these effects are completely dependent on how the salvage logging is done. It isn't always bad or good for the ecosystem. As with anything, we must weigh the positive and negative outcomes, and I want to be clear in this presentation that I am not denouncing the use of salvage logging across the board. However, if we experience more large disturbances (such as tornados) in the future, we may end up doing more salvage logging. So it is important to understand the impacts of this practice on our forests.



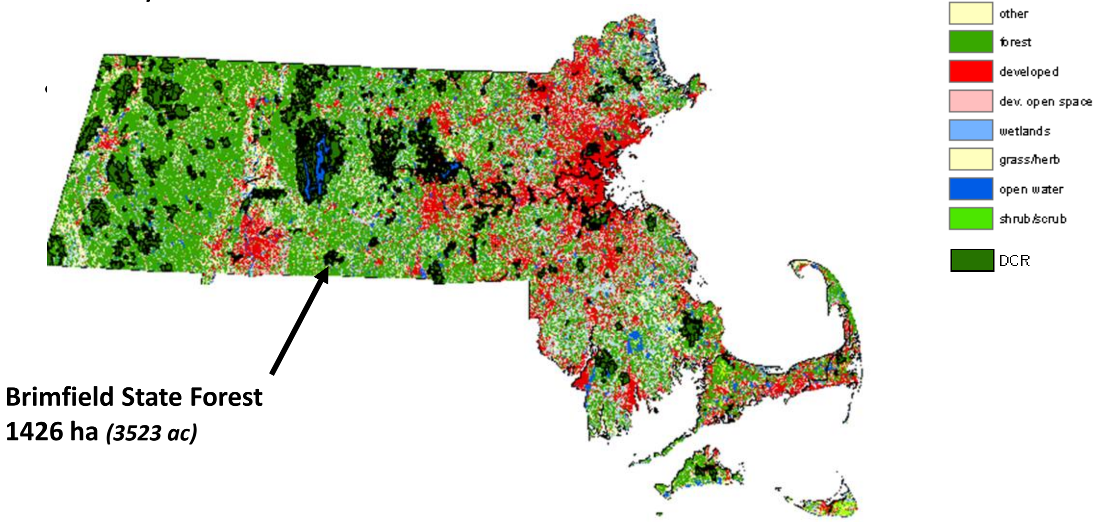
I’ll go a little more into compound disturbance, since it’s very important for forest recovery after salvage logging. Compound disturbance is a second disturbance right after the first. In a single disturbance event, damage occurs, but over time, resilient forests can grow back. However, in a compound disturbance, another disturbance event happens as the forest tries to recover, pushing it back even further – a double-setback, if you will. This “double-whammy” hinders forest recovery, and the forest could be more susceptible to other kinds of disturbance, such as invasive species and gypsy moth infestations.

Context of Our Study

History of Brimfield State Forest

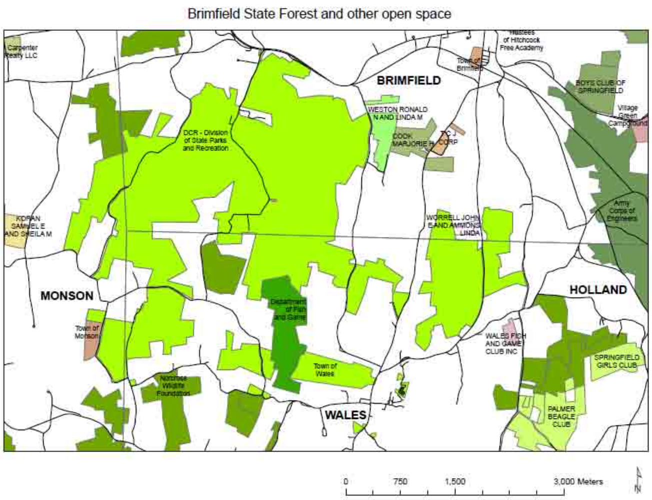
2011 Tornado

Study Area



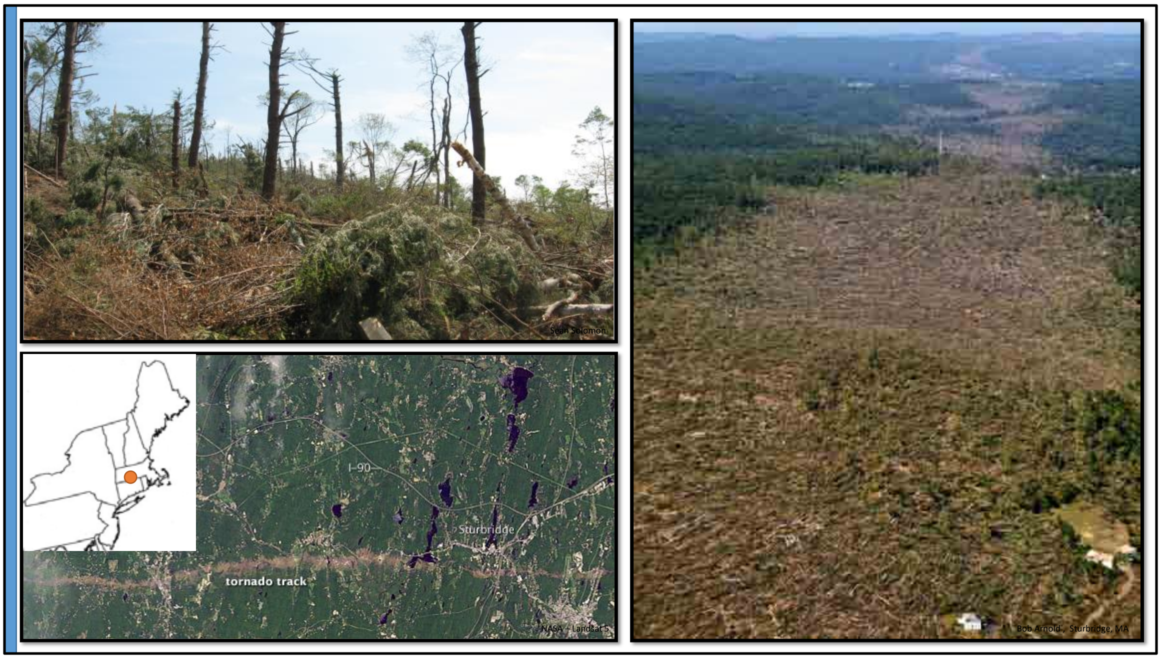
Our study area is Brimfield State Forest (BSF), a 3523 ac forest reserve within the MA Department of Conservation and Recreation (DCR) forest and park system. The dark green areas on the map are DCR lands, the arrow points to BSF.

History of Brimfield State Forest



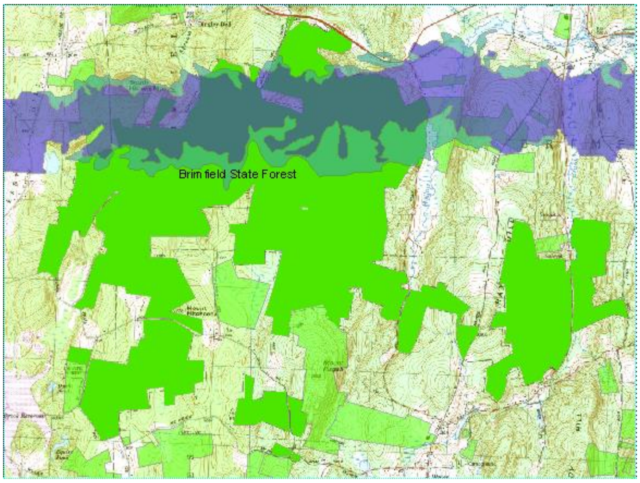
- Acquired >1920s
- CCC work > 1930s
- CFI plots > 1964
- Managed > 1960s -1990s
- Tornado > June 1, 2011
- Reserve status > 2012

History of Brimfield- The first parcels were acquired with the 1920s and were primarily abandoned agricultural land. The Civilian Conservation Corp (CCC) were active in the 1930s and created infrastructure such as shelters, roads, and fire ponds. In the 1960s, the first long-term forest monitoring plots (CFI- contiguous forest inventory) were established. Between the 1960s and 1990s, the forest was actively managed for timber and fuelwood. The tornado occurred on June 1, 2011. The forest was designated a Reserve in the spring of 2012. This is important because reserves are the DCR's most management restrictive landscape designation. The major purpose of reserves are to let natural processes take their course. This meant that no salvage logging would take place.



June 1 2011- a tornado touched down in Westfield MA and tracked eastward ~38 miles to Charlton MA.

Tornado in Brimfield State Forest



- EF3 Tornado
  - (218-266 km; *136 to 165 mph*):
- Brimfield State Forest:
  - Total: 380 ha *(927 ac)*
  - Heavy damage: 250 ha *(618 ac)*
- Vegetation survey

Brimfield- by the time the tornado reached BSF, it was an EF3 tornado with wind speeds between 136-165mph. The tornado affected over 900ac of the forest, with 618 receiving heavy damage. Since it had been designated a reserve and no salvage logging would take place, the DCR took the opportunity to conduct a vegetation survey to quantify changes in forest structure.

Our Research

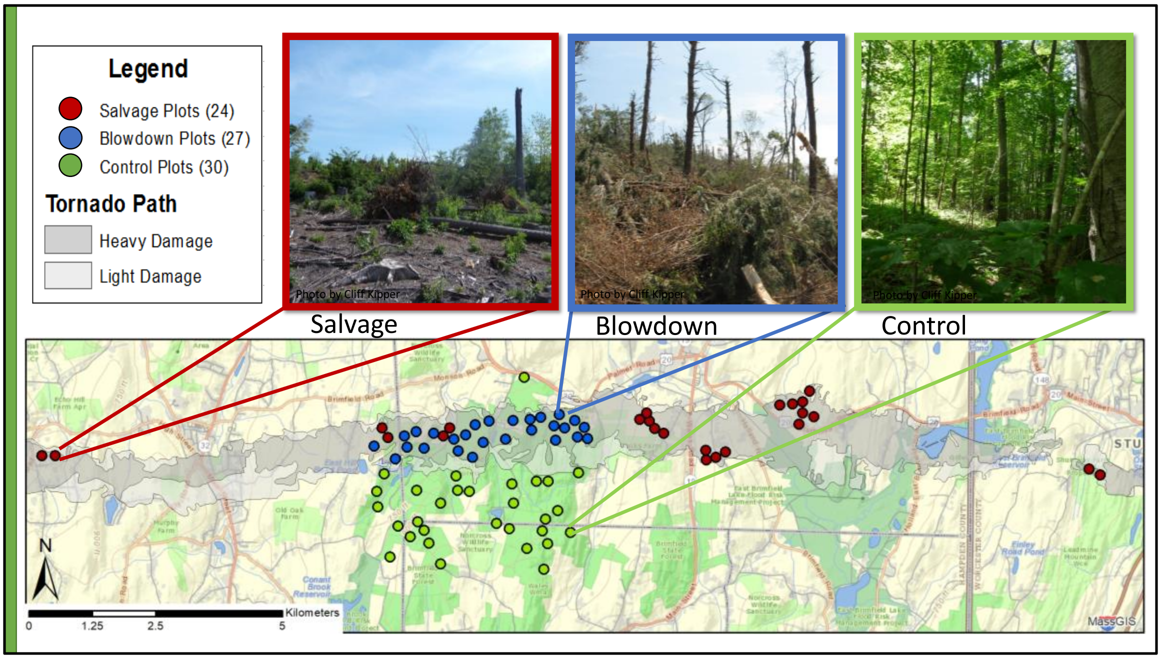
Research Design

Research Objectives

Our Study

- Tornado-damaged areas
  - Within BSF: No salvage logging
  - Outside BSF: Salvage logging (private landowners)
- Unaffected areas
  - Within BSF: No tornado

Our study incorporated two types of land: the land affected by the tornado (purple) and unaffected (green).
The tornado-damaged areas inside Brimfield State Forest (BSF) remained as they were: no salvage logging or clean-up (blue arrow).
The tornado-damaged areas outside BSF owned by private individuals experienced salvage logging (red arrow).
The rest of BSF was unaffected by the tornado (green arrow).



This allowed us to set up a study with three plot types. These plots were initially measured in 2012 and measured again in 2017.
Salvage plots (red) were hit by the tornado and subsequently salvage logged by private landowners.
Blowdown plots (blue) were hit by the tornado, but the state forest left the trees on the ground.
Control plots (green) were not affected by the tornado.

Research Objectives & Questions

- **Objective**: examine forest regrowth after the 2011 tornado
- How do tornados and salvage logging affect:
  - **Overstory** conditions?
  - **Regeneration** growing back?
    - **Coarse Woody Debris** impacts on regeneration?
- What can we do today in reaction to natural disturbance to ensure we have a healthy forest in the future?

Our main goal of this research is to examine forest regrowth after the 2011 tornado. We want to determine the effects of the tornado and salvage logging on future forest structure and composition. Specifically, we're exploring effects on the overstory trees, the regeneration growing back, and the dead wood on the ground. Additionally we'd like to use this research project as a planning opportunity. If New England experiences another tornado, what have we learned from this one? How can we encourage the regrowth of a healthy forest in a way that also keeps people safe?

Field Work & Methods

Vegetation Measurements

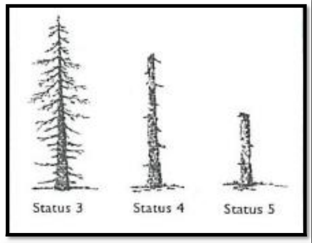
Methods: Plot Measurements

- Initial survey 2012
  - Remeasured 2017
- Plot > 1/5 acre (809.4 m^2)
- **Measurements**
  - Trees
  - Regeneration
  - CWD

Methods-Plot Measurements- we conducted the initial survey in 2012, and remeasured each plot in 2017. On the 1/5 acre plots, we collected tree, regeneration, and down-dead wood (cwd- coarse woody debris) information.

Methods: Tree Measurements

- 2012: Live and standing dead
- > 5" (12.7 cm) DBH
- Metrics Included:
  - Species
  - Status
  - DBH
  - Height
  - Loss agents including:
    - 52) > 45 degrees from vertical
    - 76) > 75% live crown loss
- 2017: Matched trees



Tree- For all live and standing dead trees (diameter at breast height (4.5') dbh >=5"), we identified species, measured height and dbh, and documented loss agents that included tornado-specific damage such as lean>45 degree and live crown loss 75%.

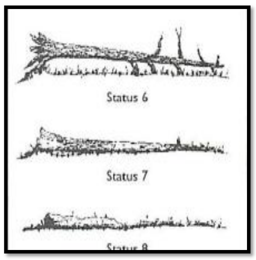
Methods: Regeneration Measurements

- 2 subplots
  - 6’ (1.8 m) radius
- Live tree species
  - < 5” (12.7cm) dbh
  - Tally - size class
- Shrubs and forb species
  - 25% cover classes

Regen- in 2 6' radius subplots, we tallied tree species by size class for all stems with dbh<5” , and we identified shrubs and herbaceous plants and binned them into 25% cover classes.

Methods: Coarse Woody Debris Measurements

- 100’ (30.48m) transect
- Dead, down wood
  - > 3” (7.6cm) diameter & 3’ (0.9m) long
    - species
    - diameter
    - length
    - decay class



CWD-coarse woody debris- in a 100' transect, we identified species and measured diameter, length, and decay class for all dead down wood >3” and at least 3' in length.

This photo shows what it was like in the “tornado zone” – lots of regrowing saplings and dead wood everywhere!

Findings & Results: 6 Years

Overstory & Live Tree Results

Regeneration Results

Coarse Woody Debris Results

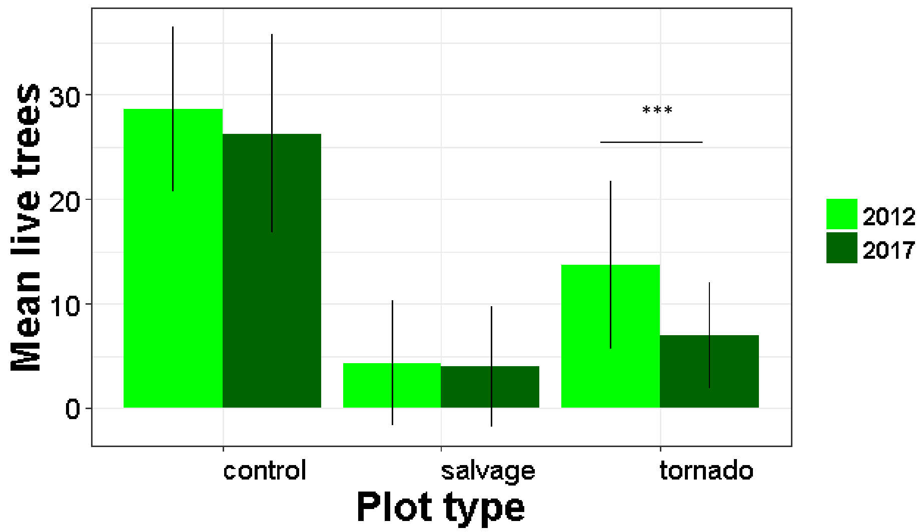
Overstory & Live Trees

Temporal Comparison

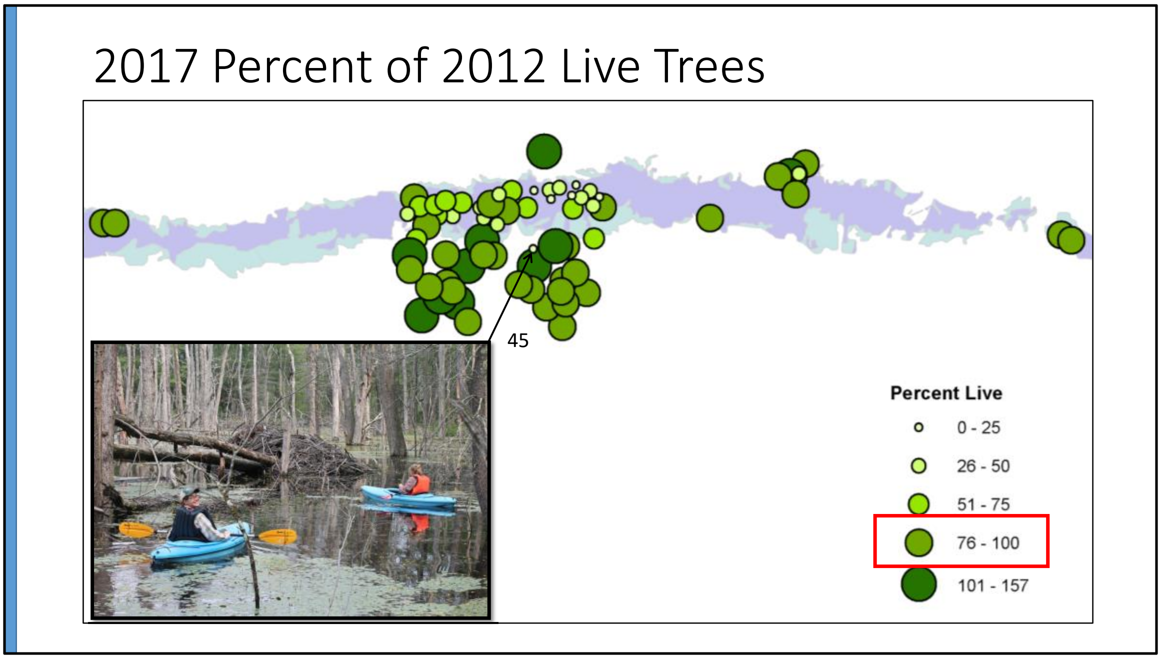
Species Composition

Mechanical Damage

Live Trees: 2012 vs. 2017



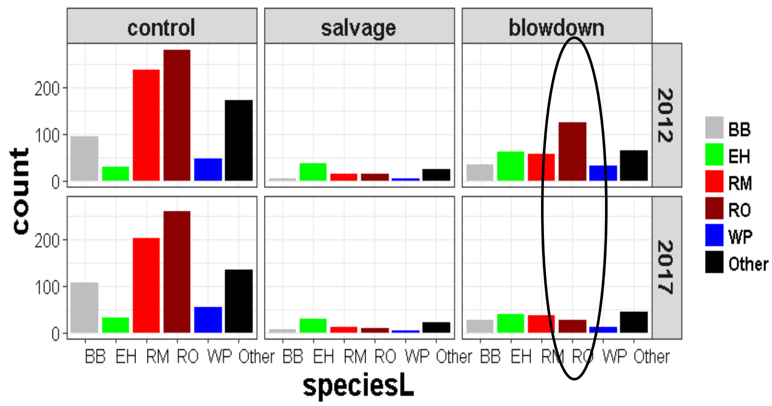
While there was a slight decline in mean live trees in the control and salvage strata in 2017, there was a significant decline in the tornado plots.



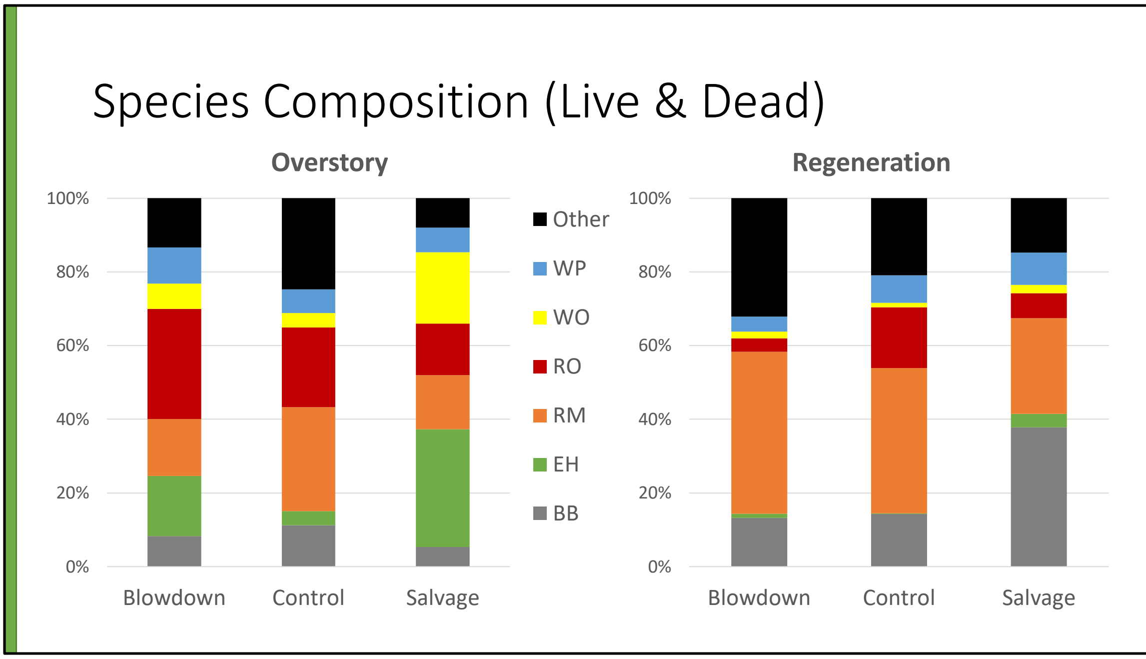
To look at the change in live trees spatially, each circle represents a plot location- and the size and color of the dots represent the percent of live trees compared to 2012. You can see the high mortality of the blowdown plots and also the outlier in the control plots (the photo tells the story). Beavers dammed a waterway, which flooded the plot and killed all 40 of the trees that were live in 2012.

Live Tree Count Change Over Time

- BB- black birch
- EH- hemlock
- RM- red maple
- RO- red oak
- WP- white pine
- Other



To take a closer look at the % live- Here is a comparison of common species. We don't see much change in composition in the control and salvage plots, although we can see the RM dip (driven by the flooding we saw in the previous slide). However, in the blowdown plots there is a substantial decline in red oak. This is an oak-dominated forest. They comprised a majority of the canopy. Many of the trees we surveyed in 2012 were alive, but they were heavily damaged and were not able to persist.



This figure looks at species composition a little more in depth. On the left, we have overstory species composition in 2017. Both blowdown and control plots have 45-50% of their composition in red oak and red maple (red and orange). However, in salvage plots, red oak and red maple are only about 25-30% of the composition. This may be because these trees were damaged and then removed during salvage operations. Additionally we see that eastern hemlock (green) is higher in blowdown and especially salvage plots. This is likely because hemlock trees were shorter – in the midstory – when the tornado hit, and thus did not take the brunt of the wind like the tall canopy red oaks. Therefore, when the 40-60 foot tall canopy trees were blown down in the tornado, the 10-20 foot tall hemlock trees became the new canopy.

On the right, we have regeneration species composition in 2017. Let's look first at red maple (orange) and black birch (gray). These are early-successional species, meaning they come back quickly after a disturbance. There are a lot of these species in all plot types, but there is more in both blowdown (approx. 58%) and salvage plots (approx. 62%). Compare this to red oak, a species that takes longer to regenerate. There is more red oak (red) in control plots and not very much coming back in blowdown or salvage plots.

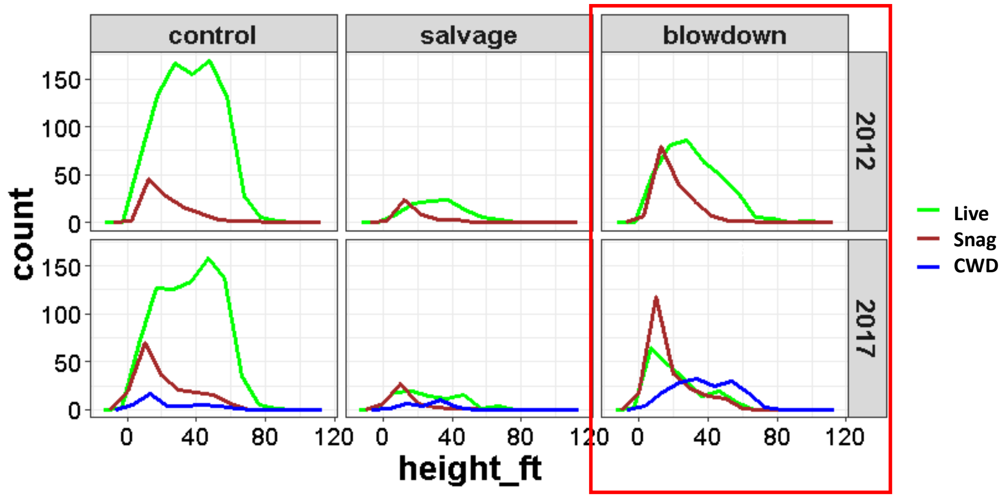
Understory Change Over Time

2012

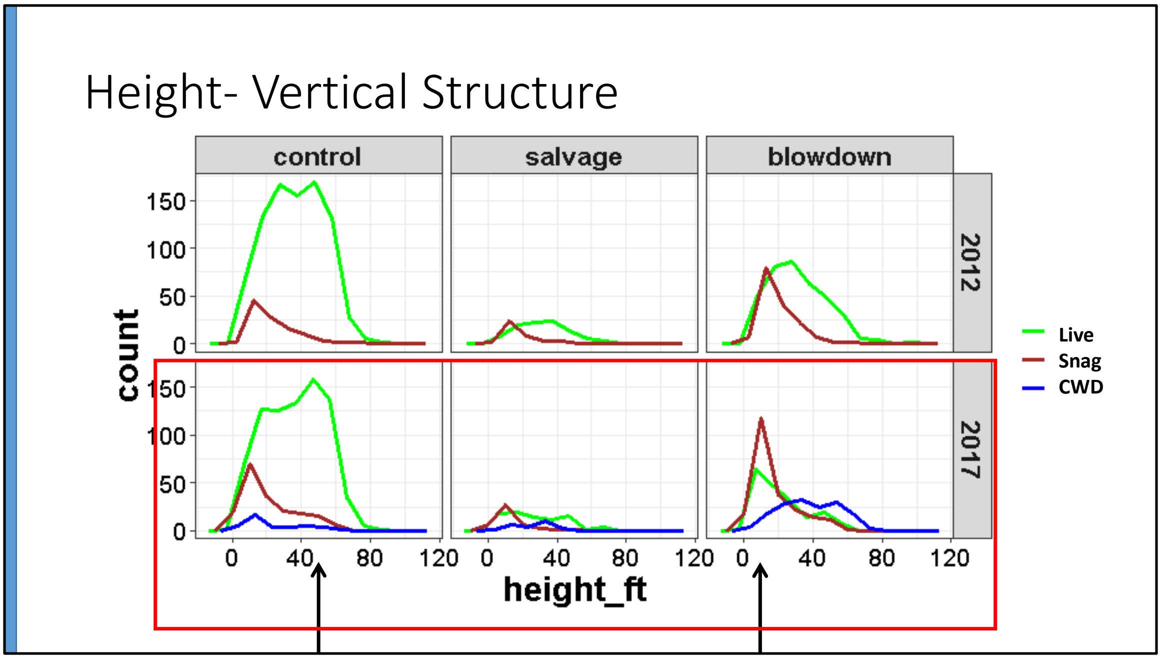
2017

These photos were taken at the same plot, first in 2012 and then again in 2017. You can see that the regeneration is growing back quickly in 5 years!

Height- Vertical Structure



This figure shows changes in tree height, which helps us think about vertical structure. First, focus on the tornado plots between 2012 and 2017; we see the shift from live tall trees to long cwd (the blue line) and an increase in tall snags-dead standing trees (the brown line). This is the mortality we saw in the previous slides- those tall live trees were lying on the ground hanging on by a root, or heavily damaged with too few live branches.

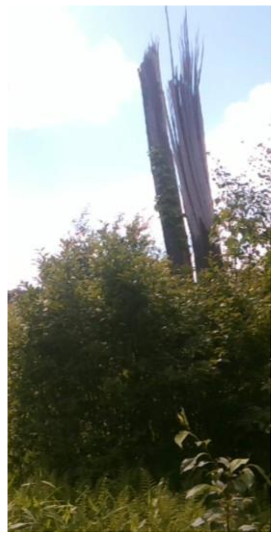


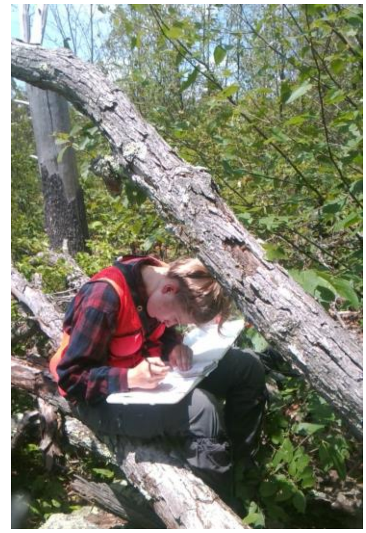
Now focus on 2017-
In this histogram, we see that most of the live trees in the control plots are around 45’ tall, contrast that with the blowdown plots where most of the live trees are less than 10’ tall.

This image of the blowdown area shows the simple vertical structure we expect to see in the stand initiation phase, where we have one cohort, or age class, and ample resources. This early successional forest provides habitat for species that require these conditions (such as the ruffed grouse and New England cottontails).   The tornado zone increases the overall diversity of the forest.

Site Factor Contribution to Loss Type

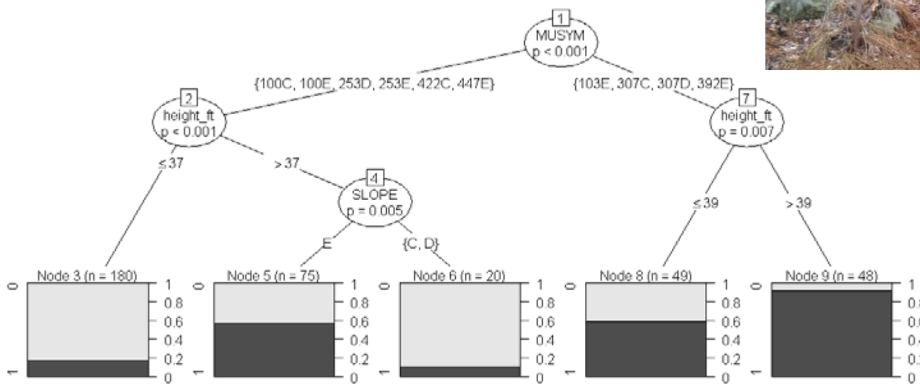
- Tree
  - Species
  - Height
  - DBH
- Plot
  - Soil
  - Slope
  - Aspect
  - Elevation





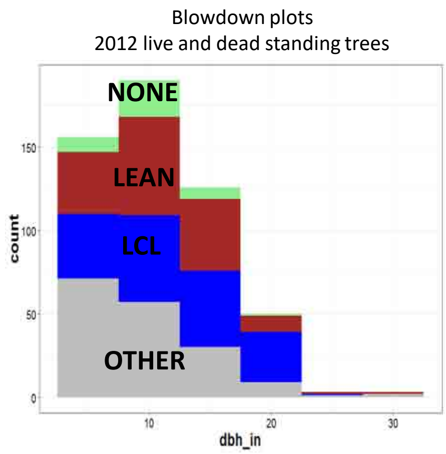
I am interested in the differential effects on blowdown plots and what site specific factors played a role in excessive lean and live crown loss. Did species matter, size, soil type; did topographical characteristics such as slope, aspect, and elevation affect wind speeds and subsequent damage?

Live Tree Lean



This classification tree (*an analysis which divides a dataset into subsets that help explain the response)* shows that 90% of the time trees taller than 39 feet that occurred on one of 4 soil types were classified as having lean >45 deg. This makes sense, as these soils are characterized as steep or extremely stony *(with root growth restricted by the substratum)*, and so trees may not have been able to attain deep root systems, and tall trees have more surface area for the wind to hit. Here is a picture from plot 4, which has soil type 307D.

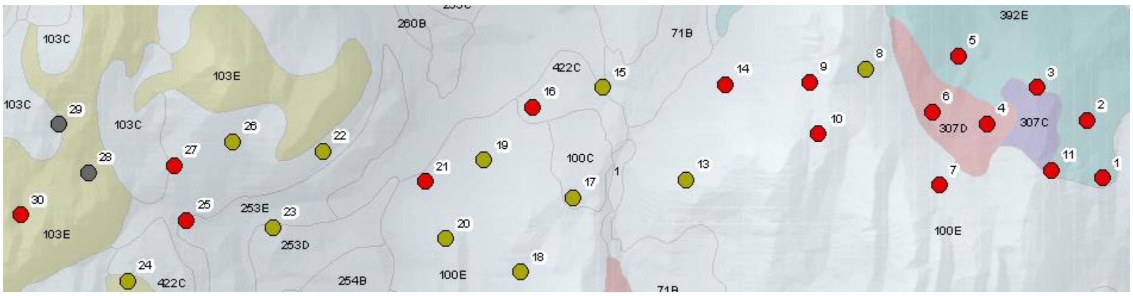
Live Crown Loss (LCL) and more



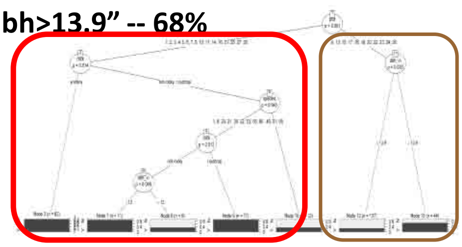
- **Larger diameter trees more likely to suffer major tornado damage**

The data explain some of the lean, but what about the live crown loss, and trees like the photo on the left? That was a mature red oak with a dbh >12” and a height of at least 40’. Because of the way we collected the data, I couldn’t answer this question. However, this histogram shows that as diameter class increases, so does the likelihood of a tree being severely damaged by the tornado.

Heavy Tornado Damage



- Red
  - **Extremely stony -- 95%**
  - **Not white oak, black birch, or hickory &**
    - **Rock outcrop -- 92%**
    - ? **Not rocky & <= 13" dbh -- 91%**
    - Not rocky & > 13" dbh – 33%
- **Gold**
  - **If dbh>13.9" -- 68%**

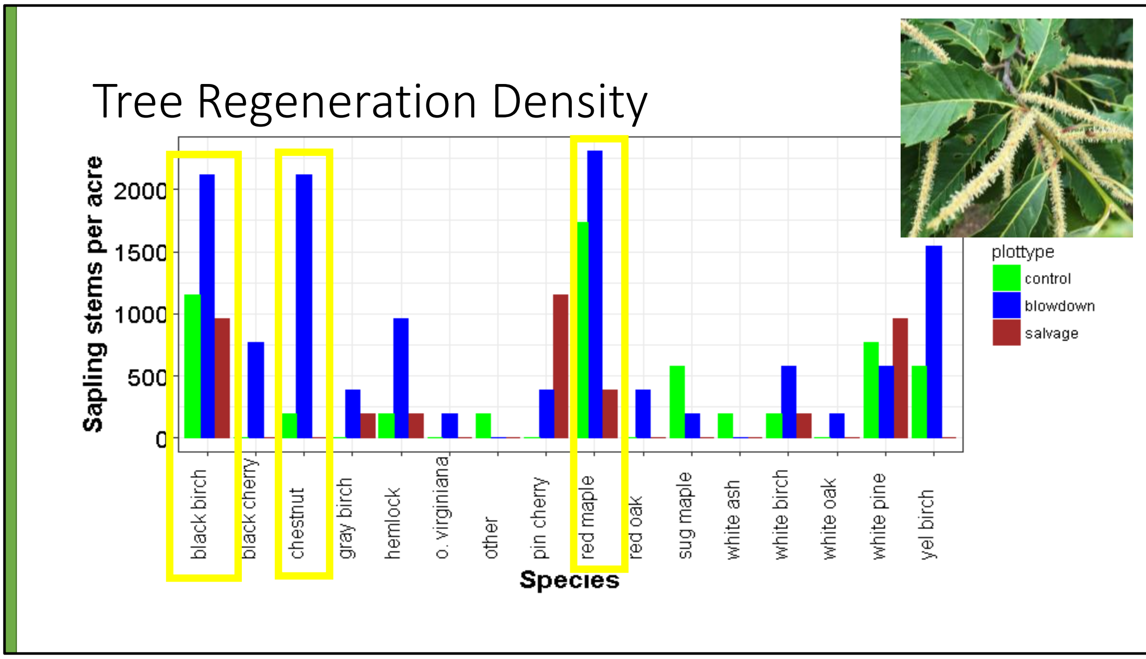


Since I couldn't answer the question about why some trees tipped and some lost their crowns, I needed to ask a different question. Where did the heavy damage occur, or what species were heavily damaged. For all blowdown plots, I grouped the trees into two categories, whether or not they had heavy damage (Y or N). Yes meaning either live crown loss >75% or lean > 45 degrees from vertical. I ran a classification tree that included plot as a variable (in addition to species, dbh, soil, slope, aspect, and elevation). Plot was the most important variable. Here I mapped the split in the classification tree and color-coded the plots. Gold is the split on the right, red on the left. Diameter is a factor in the gold plots, but only 68% of those with a dbh >13.9" suffered heavy damage in those plots. In the red plots, on extremely stony soils 95% of the trees suffered heavy damage. On soils with a rock outcrop designation, species other than white oak, black birch, or hickory were 92% likely to suffer heavy damage. Unexpectedly, on the not rocky soils, smaller diameter trees (that weren't white oak, black birch, or hickory) had a greater chance being heavily damaged. Since I ran this analysis last night, I haven't had a chance to think too much about why we see this unexpected response. (Let me know if you have any ideas).

Regeneration

Density: Amount of Seedlings

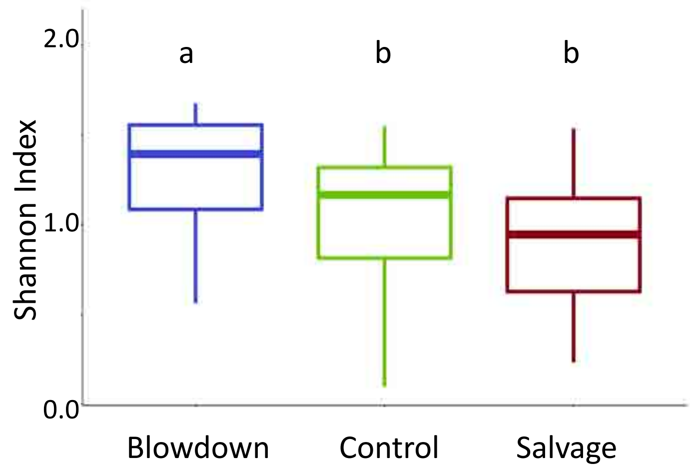
Diversity: Different Species of Seedlings



This graph shows the density (saplings per acre) of regenerating tree stems on each of the three plot types. We can see that disturbance-adapted species, such as black birch, yellow birch, American chestnut, and red maple, are coming back strongly in blowdown plots (blue). Unfortunately, American chestnut will likely eventually die off due to the chestnut blight. There are also some species that are doing well in salvage plots. These include black birch, pin cherry, and white pine. Black birch and pin cherry are early-successional species. White pine may have seeded in from dropped pine cones. It likes open light environments, so that could be why it's doing well in salvaged sites. It is important to note here that even though there is lots of sunlight in salvaged plots, other factors could hinder regeneration success. Some of these factors include deer browse, low soil moisture, and compaction from the equipment used in salvaging operations.

Tree Regeneration Diversity

- Highest diversity in **blowdown** plots
- Salvage logging may have initially **homogenized regeneration composition**
    - **Black birch** and **red maple** dominate



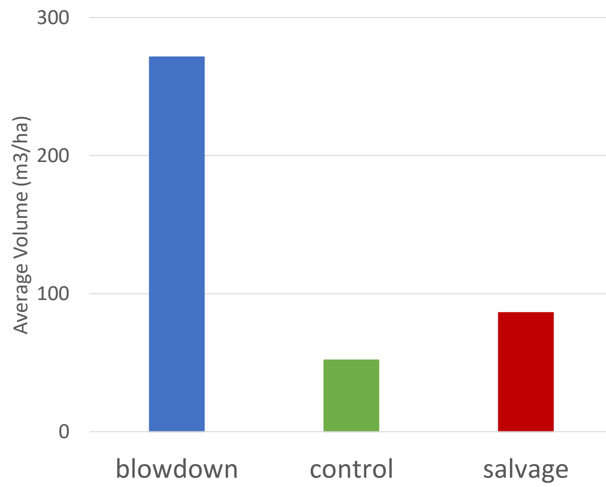
This graph shows how tree regeneration diversity changes in different plot types (note: this only includes tree seedlings/saplings, no wildlife diversity). Diversity is measured by the Shannon Index, which takes species abundance and evenness into account (for more information, see Wikipedia: https://en.wikipedia.org/wiki/Diversity_index#Shannon_index). Higher Shannon Index values mean higher diversity. Here, we see that the highest diversity occurs in blowdown plots. So despite the tornado disturbance, many different species of trees are growing back – even more than in the control plots. This may be due to an open canopy providing sunlight, seed source from surrounding trees, and protection from dead wood on the ground. We see the lowest regeneration diversity in salvaged plots. This means that fewer kinds of species are growing back. From the last slide, we saw this was mostly black birch and red maple, which are disturbance-adapted species. This suggests that the compound disturbance from salvage logging may have homogenized regeneration composition toward these disturbance-adapted species. It is important to monitor regeneration as the forest regrows to see if these results change over time.

Coarse Woody Debris

Influences on Regeneration Success

Coarse Woody Debris Volume

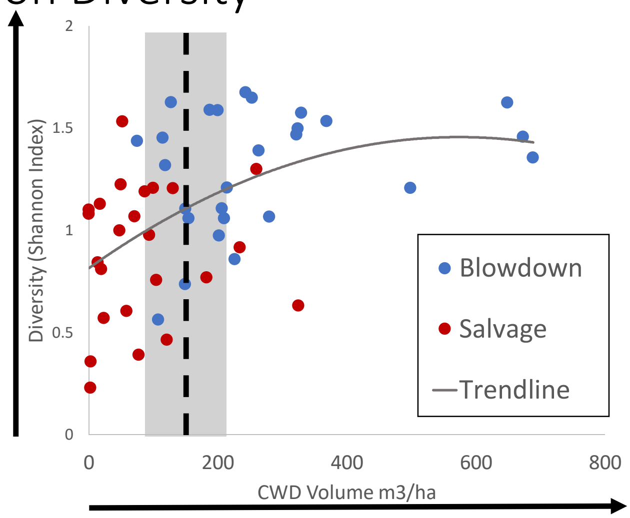
- Coarse Woody Debris (CWD): fallen dead trees decaying on the ground
- 5x more on Blowdown than Control
- **Does CWD hurt or hinder regeneration diversity?**



Coarse woody debris is the dead wood left to decay on the ground. We see that there is five times more of it in blowdown plots than in control plots. We expected this because the CWD in the blowdown plots was not removed after the tornado. Salvage logging removes most of the CWD. How might this increased volume of CWD affect regeneration success and diversity? You might think more CWD would block sunlight, making it harder for seedlings to establish. But maybe it’s also harder for deer to get in there and eat the seedlings, or the decaying wood makes great new soil with enough moisture for regeneration to thrive. Salvage sites are open and have lots of sunlight, but does other vegetation (ferns, raspberry) shade it out quickly because of so much sun? Or is the soil too dry and compacted for regeneration to grow successfully?

CWD and Regeneration Diversity

- Seedling diversity is **higher** on sites with more CWD
- Retaining **more CWD** (less intense salvage) could help many diverse species regenerate



To try to answer this, I graphed the volume of CWD against the Shannon Index for regeneration diversity. Higher CWD means more dead wood on the ground, and higher Shannon index values mean higher diversity in regenerating seedlings and saplings. Here we only look at blowdown and salvage plots, since control plots did not experience a disturbance. Blowdown plots (blue) have more CWD because they were not salvage logged. They also tend to have slightly higher seedling diversity. Salvage plots have less CWD and slightly lower seedling diversity. The line represents a trend – not a strong one, though – of higher regeneration diversity in places with more CWD. It appears that more CWD helps diverse trees to regenerate, perhaps because of what we mentioned on the last slide: protection from deer browse and better soil.

There are some red dots (salvage) mixing in with blue dots (blowdown) on this graph, and we can see that salvage sites that had more CWD generally had higher seedlings diversity. This points to a happy medium for forest management: perhaps if we salvage log but don't pick up *all* of the dead wood – instead, leaving some dead wood on the ground – we can maintain regeneration diversity. This is great news since we'll still want to take protective measures (i.e. fuels reduction) through salvage logging, but leaving some dead wood on the ground may not deal that "double whammy" to the forest.

Implications: What does it mean?

The Future of the Forest

Management Implications

What Does This Mean for the Forest?

Finding	**Interpretation**
Seedlings and saplings are growing back rapidly	This forest is resilient to heavy damage
Salvage logged sites have lower species diversity	The future forest may not be as diverse (more disturbance-adapted species)
Tornado has left a patchy distribution of vegetation	Blowdown areas provide good habitat for early-successional species (grouse, rabbit) and landscape diversity

To sum up, these are our major findings:
We see lots of seedlings and saplings growing back rapidly on all plot types, meaning that this forest is already recovering from the tornado. This shows resiliency in the face of a large disturbance, which is something we love to see!
In general, salvage logged sites had slightly lower regeneration species diversity than control or blowdown sites. This means that the future forest may be composed of more disturbance-adapted species such as red maple and black birch, but it is too soon to make long-term predictions. We should monitor the regeneration going forward to see if the composition and diversity change as the forest recovers.
Finally, the tornado has left a patchy distribution of vegetation across the landscape. This is incredibly important to landscape-level heterogeneity, which increases overall diversity. Blowdown areas provide great habitat for early-successional species such as grouse and rabbit, which control areas remain good habitat for other species.

Take-Home Message

- Natural disturbance is a reality
  - Positive effects: diversity in early-successional habitat
  - We may have to be prepared for more frequent and intense disturbances
- What we do after a disturbance may affect how the forest grows back
  - **Intense** salvage logging may alter future species composition (reduce diversity)
  - Dead wood left on the ground may help increase sapling diversity

There's no way we can avoid natural disturbance: it's a reality here in New England. Wind disturbance does have some positive effects on the ecosystem, notably creating diversity in early-successional habitat. But the downsides are costly. We may have to be prepared for more frequent and intense disturbances in the future, so we can use the 2011 tornado to learn and plan.

What we do after a disturbance may affect how the forest grows back. Our results indicate that *intense* salvage logging may reduce species diversity, and this may continue into the future. But dead wood left on the ground may help to increase seedling/sapling diversity. Therefore, medium-intensity salvage logging, which involves removing only some of the dead wood (and leaving dead wood in some places), may be a great compromise that mitigates fire risk but also promotes forest regrowth.

Take-Home Message

- We need to plan and act today so we have a healthy forest in the future
  - Encourage **high regeneration diversity** to promote disturbance resiliency
  - **Lower-intensity salvage logging** may have minimal affects on the future forest
  - Leave some **dead wood** on the ground to foster species diversity
  - Maintain a **heterogeneous landscape** to retain one in the future

Our management actions have an affect on how the forest regrows. In case we experience more large tornados in the future, we need to plan and act today so that we can maintain our healthy northern hardwood forests into the future. These management actions involve encouraging diverse regeneration to promote disturbance resiliency, which may be achieved through low-to-mid-intensity salvage logging that purposely leaves some dead wood on the ground. This low-to-mid-intensity salvage logging may have very minimal negative effects on the forest, but great positive effects in mitigating fire risk for us. Overall, if we strive to maintain a heterogeneous, diverse landscape today, we can retain a healthy, diverse, and resilient forest into the future.

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Questions?