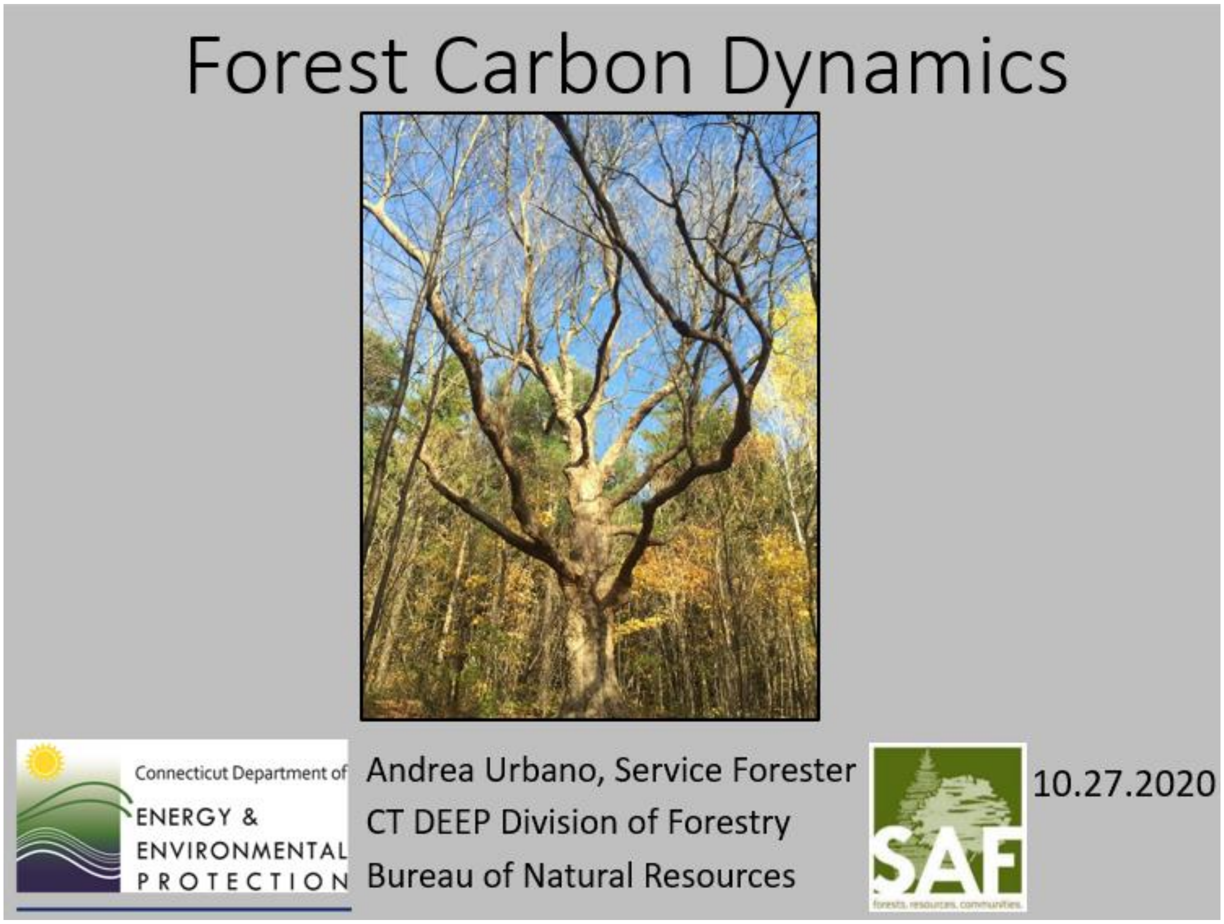

I am Andrea Urbano, a service forester with CT's DEEP. I am happy to be able to share with you some information on forest carbon accumulation dynamics. I am able to do so, in part because I earned my M.S. in carbon forestry at UVM. As you all know, this is a hot topic in regards to managing forests today, in the face of climate change. It's become important for natural resource professionals, landowners, and policy makers to understand and be able to communicate forest carbon dynamics. I hope to provide you with a basic understanding of forest carbon. Please feel free to contact me any time with additional questions or for additional resources.

Contact info:

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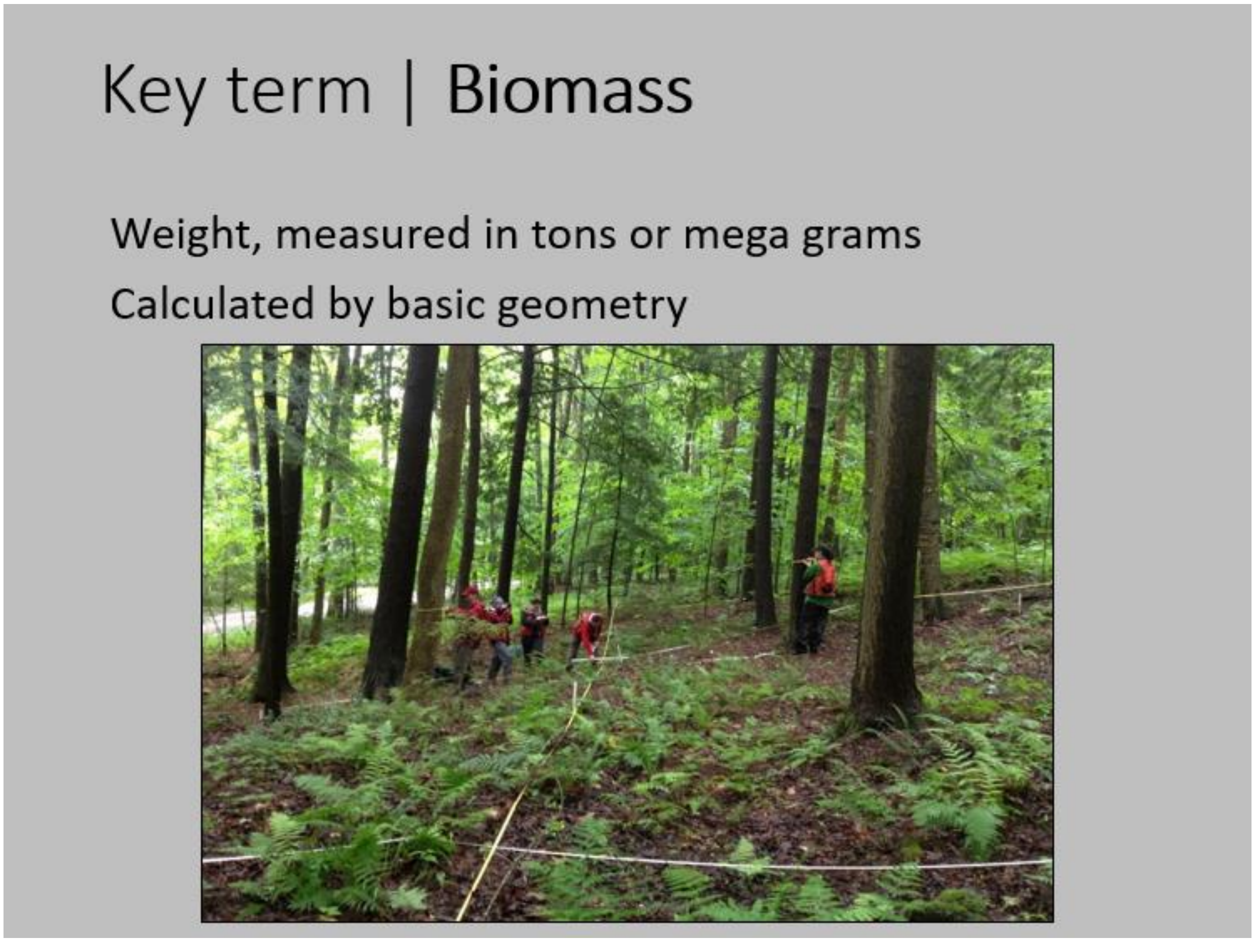
860-422-3034



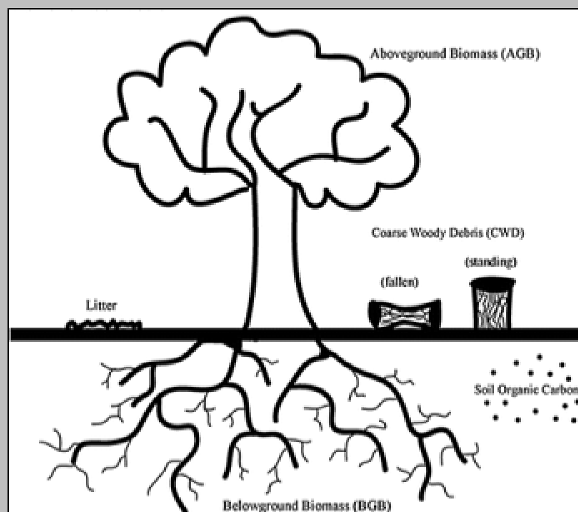
Biomass, or woody plant material, can either be aboveground or below ground. It is a weight, measured in tons or mega grams per acre, and is calculated by gathering tree dimensions such as height, DBH, taper function, decay class (if dead), etc.

Carbon is about 50% of biomass estimates.

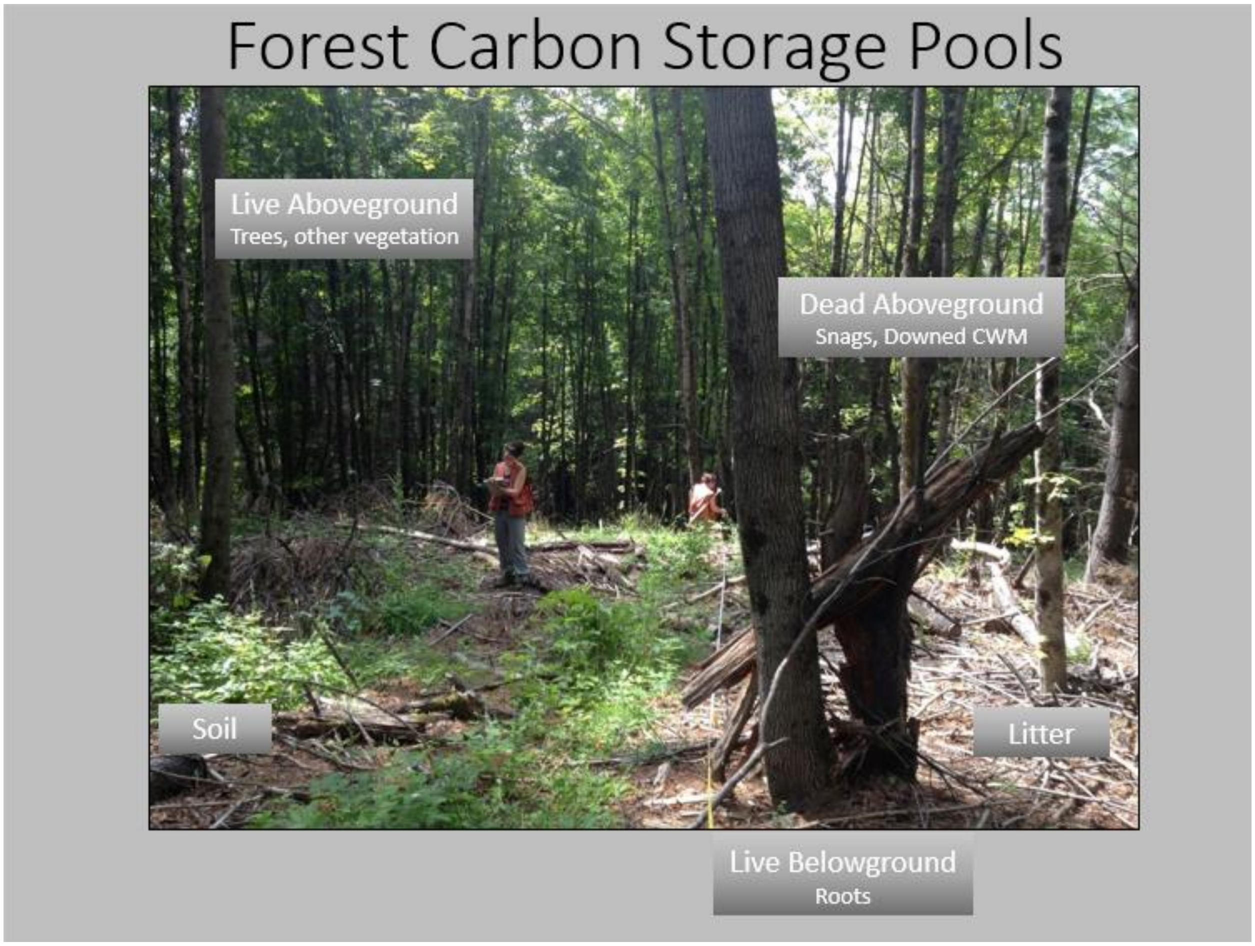
Key term | Carbon Pool

Part of the forest that **stores** carbon

It can accumulate or lose C over time



A carbon pool is part of the forest that stores carbon. The amount of carbon stored in any one pool changes over time.

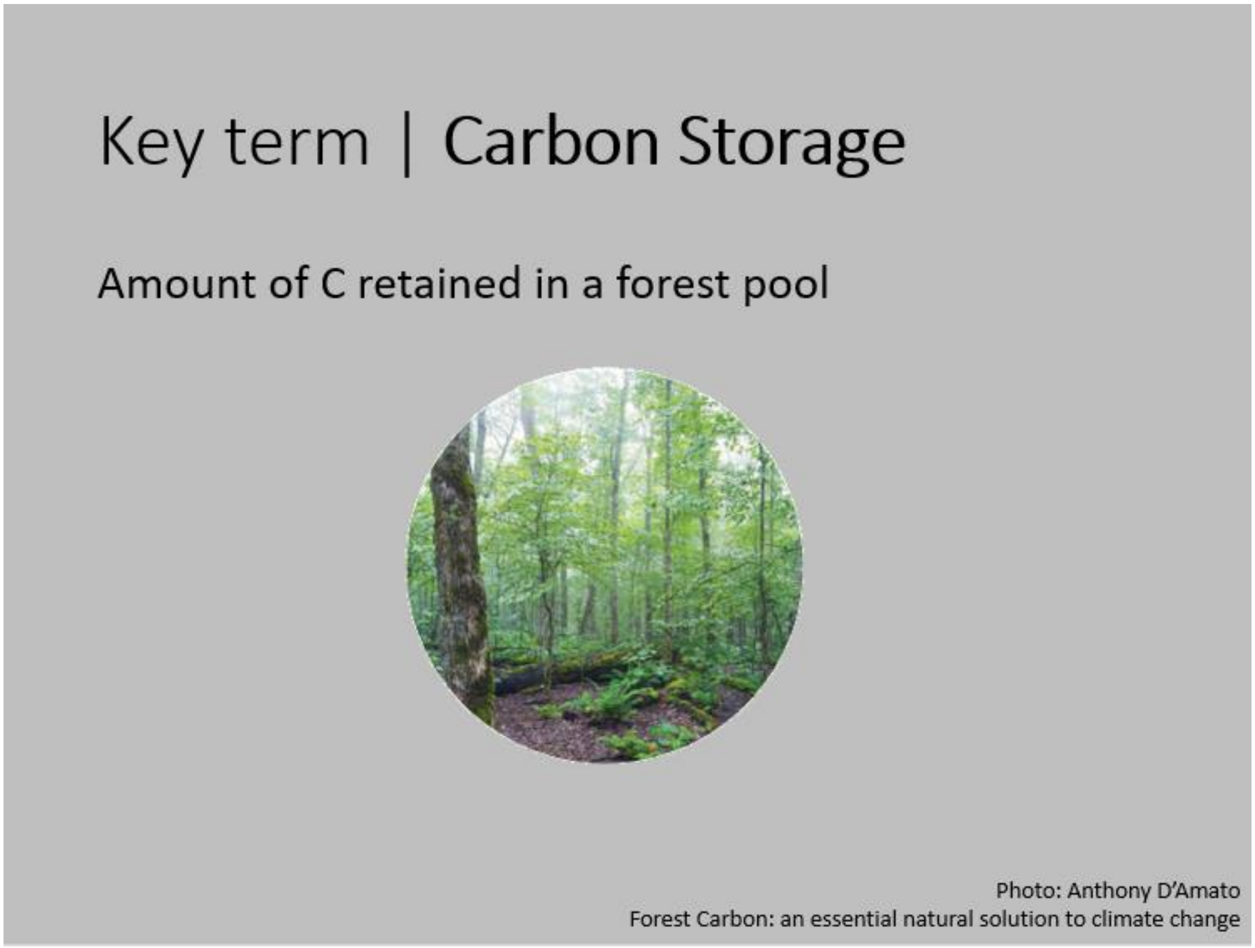


Carbon is stored, or “pooled” into these structural components of a forest:

1. Live aboveground (trees and other vegetation)
2. Dead aboveground (standing dead trees, downed coarse wood materials)
3. Litter
4. Soil
5. Live belowground (roots)

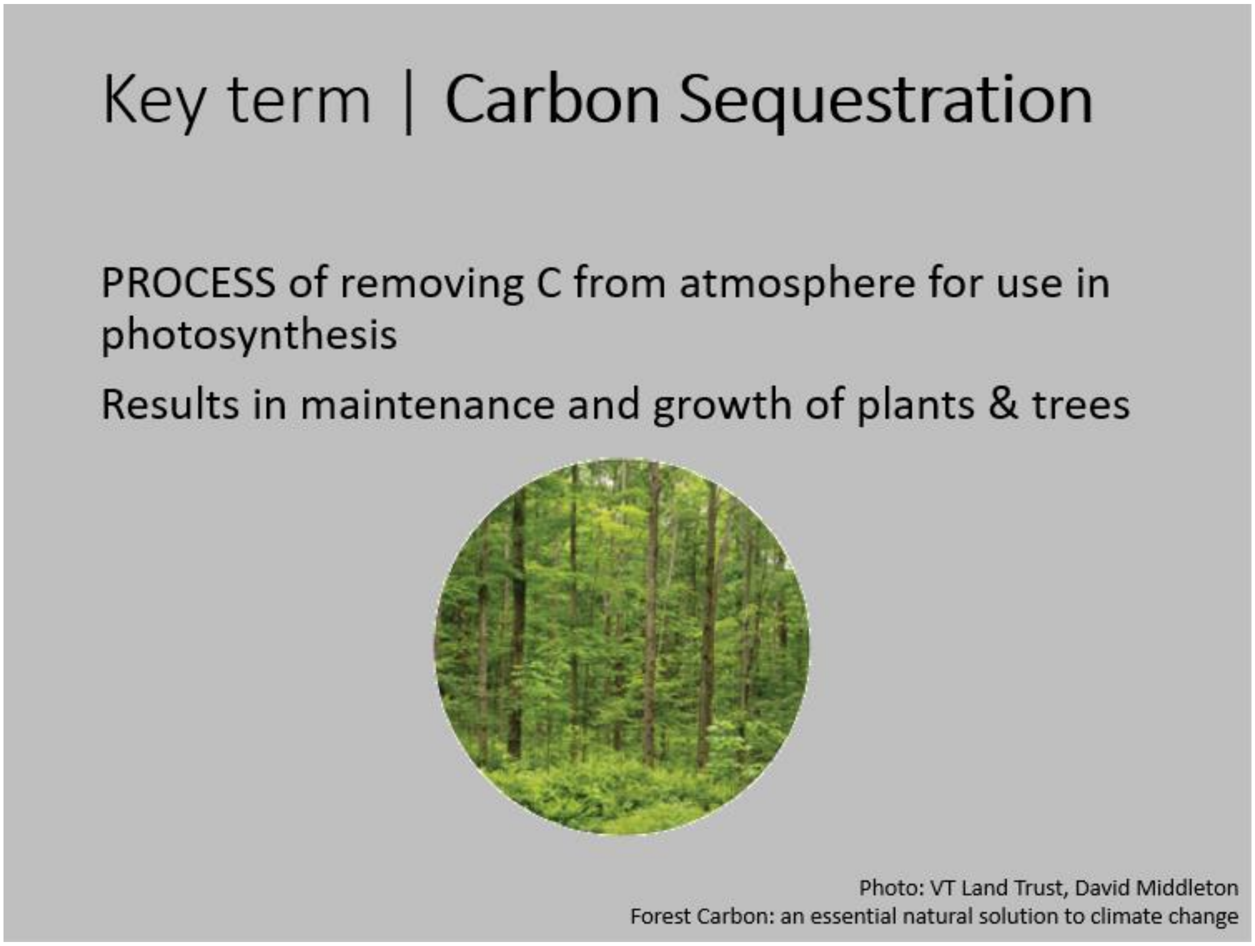
As previously mentioned, each pool can accumulate or lose carbon overtime, so the amount of carbon stored in any one pool changes with time. The factors that influence the amount of carbon stored in each pool are:

1. The age of the forest (stand age)
2. The tree species comprising the forest (species composition)
3. Natural and human disturbances
4. Soil characteristics (texture and drainage)



So carbon storage is the amount of carbon retained in a forest pool. Unless otherwise specified it is usually reflects the total amount of carbon stored in each pool – often classified as either total aboveground carbon (total of the live aboveground, dead aboveground, and litter pools) or total belowground carbon (total of the live belowground and soil pools).

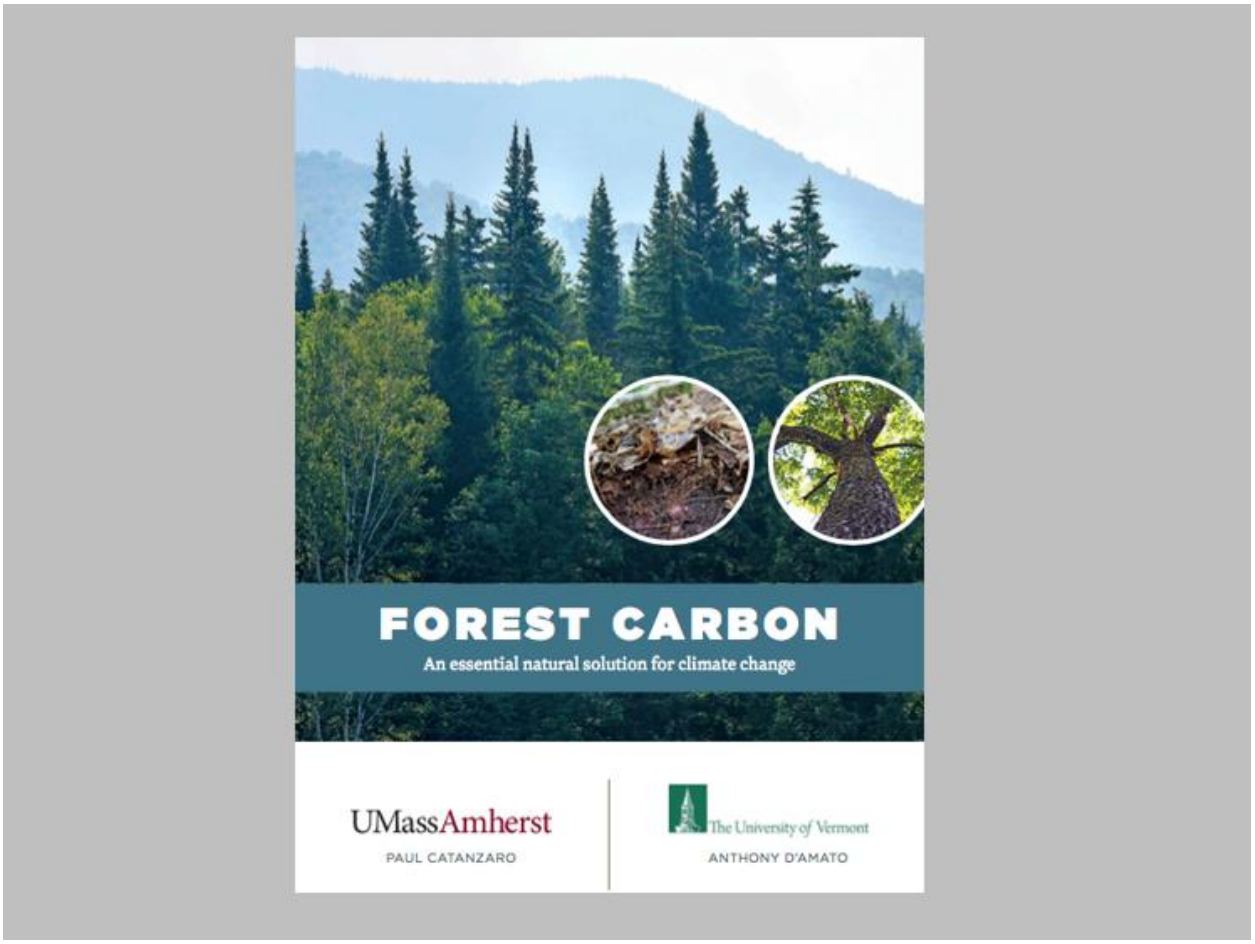
Generally, carbon storage is greater in older forests and structurally complex forests.



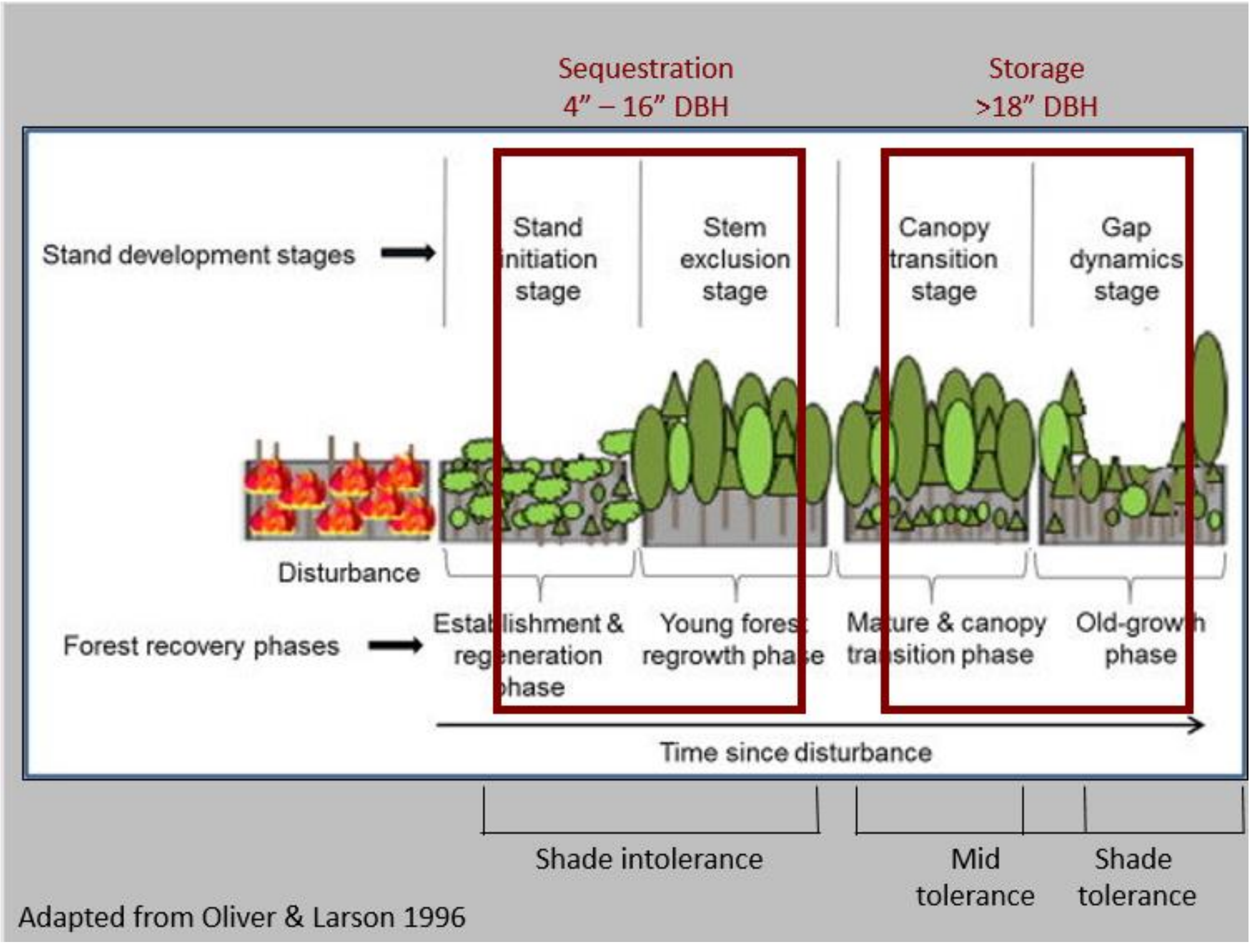
Carbon storage is not be confused with carbon sequestration. Often these terms are used interchangeably, and therefore improperly.

Carbon sequestration is the process of removing carbon from the atmosphere for photosynthesis. It therefore supports the maintenance and growth of vegetation.

Generally, carbon sequestration rates are greater in younger (20-70 year old) forests, where the growth of species is maximized - following reforestation, or regeneration after a natural or human disturbance.



For consistency, the past few definitions are from this Forest Carbon publication. To access the PDF or to request hard copies, visit: https://masswoods.org/caring-your-land/forest-carbon



It is impossible to discuss carbon accumulation dynamics without addressing principles of ecological succession and stand development.

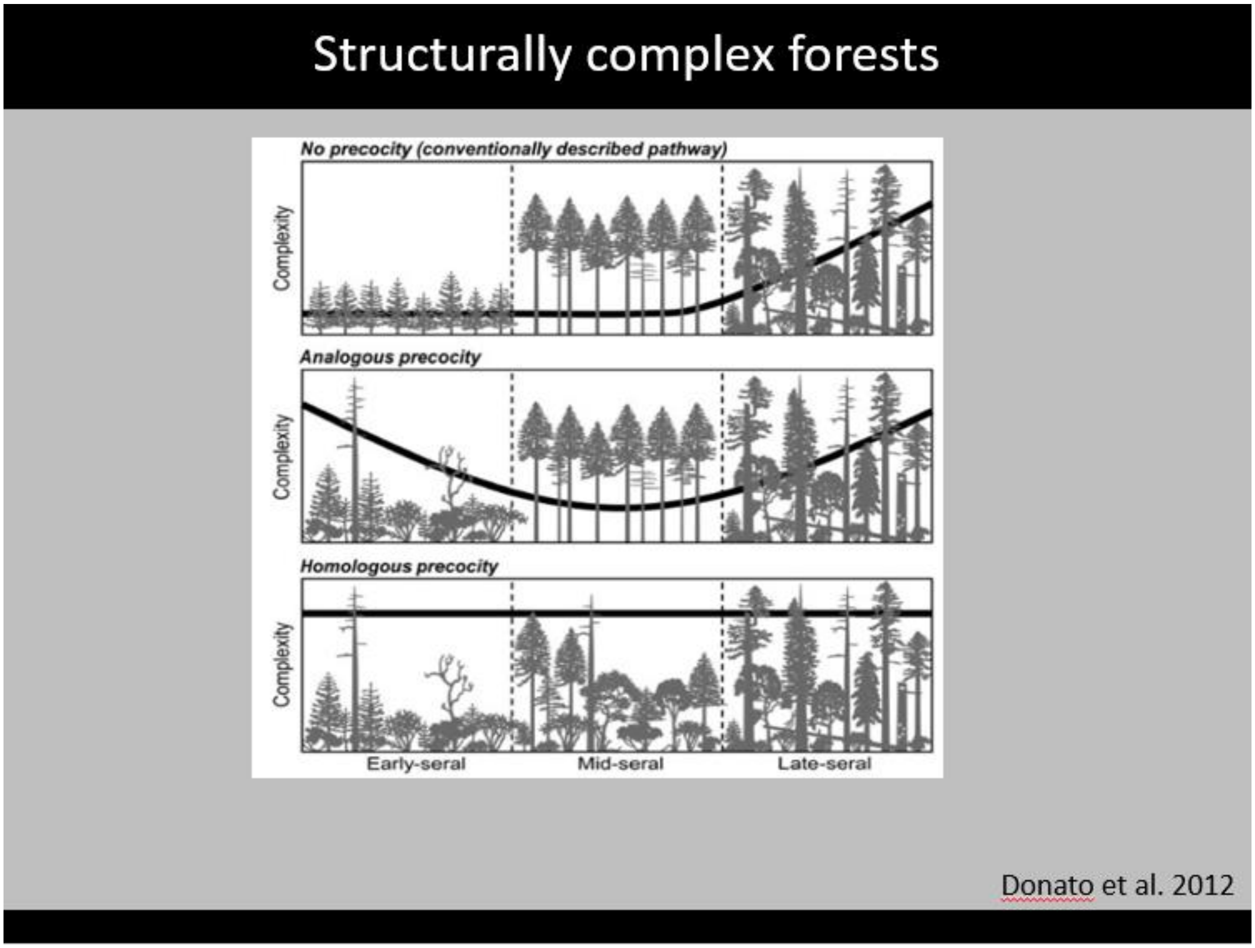
This is a conventional depiction of post-disturbance forest development indicative of forest recovery. The species composition, structure, and time elapsed since disturbance at each stage vary with the type of disturbance, dominant tree species, and site conditions.

As forests age, the species within them shift from those that are shade intolerant, to those with mid-tolerance, to those that are shade tolerant. This is the basic principle of ecological succession – the shift in tree species composition (mix of tree species) over time. This is different from forest/stand development, which is the change in forest structure (age, number, size and arrangement of living and dead trees) over time.

Both succession and development are key considerations in forest carbon accumulation dynamics. Each stage of forest succession and development provides unique benefits based on the forest's structure and composition.

A forest's maximum rate of carbon sequestration and amount of carbon storage occurs at different stages of stand development. The maximum rate of carbon sequestration occurs when trees are approximately 4" in diameter (saplings) through 16" in diameter (medium sawtimber size). Look to the red box, labeled "Sequestration" – this occurs in the stand initiation and stem exclusion stages of development. The maximum amount of carbon storage happens when trees are $\geq$ 18" in diameter (large sawtimber size). Look to the red box, labeled "Storage" – this occurs in the canopy transition and the gap dynamics stages of development. The age (structure) of the forest strongly influences both the rate at which forests sequester carbon and the amount of carbon that they store.

With this key point in mind, we must consider that there are multiple pathways of development.



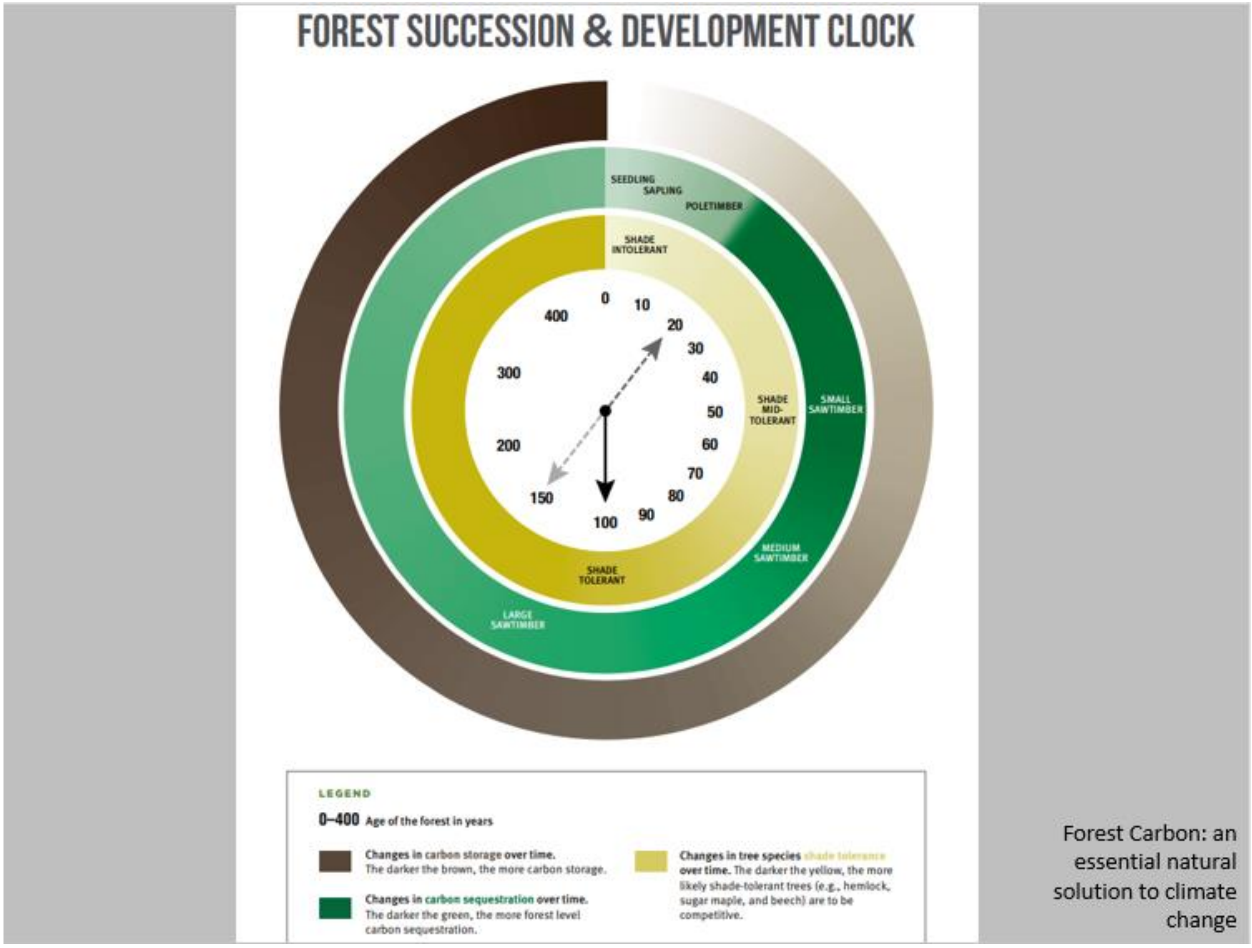
In fact, it is possible for structural complexity (and therefore greater carbon storage) to arise sooner in successional development than proposed through more conventional successional frameworks (Elger 1954. Connel & Slayter 1977, Oliver & Larson 1996).

Early onset of structural complexity post disturbance (natural or forest management) can occur in northeastern US forests (Keeton 2006), making it possible for early successional canopies to support the equally complex functioning and biodiversity seen in late successional or old-growth forests (Donato et al 2012).

Early stages of development in conventionally described pathways exhibit even-aged stands reaching structural complexity late in succession (as seen in the No precocity development pathway). This differs from other pathways of development where structural complexity is achieved early in succession (as seen in both the Analogous precocity and the Homologous precocity pathways). However, mid-seral canopy closure (as exhibited in Analogous precocity) can reduce structural complexity following early succession. Lack of canopy closure (as seen in Homologous precocity) results in sustained structural complexity throughout forest development. Donato et al. 2012.

So, depending on land-use history, disturbances, and management techniques and prescriptions, carbon storage associated with later stages of development and succession can be obtained earlier.

This indicates the ability to promote and maintain high rates of carbon sequestration and storage in our forests.



So let's look at this another way – Here you see a forest succession and development clock taken from that Forest Carbon publication –

The brown ring around the clock represents changes in forest carbon storage over time, the green ring represents changes on carbon sequestration over time, and the yellow ring represents the change in tree species shade tolerance, or succession. The darker the color, the greater the storage, sequestration, and species shade tolerance, respectively.

The clock's "time" represents stand age. It starts at 0 years (12 o'clock in an analog time clock) and the hands move around to over 400 years of age. The solid clock hand in the diagram pointing to 100 years of age indicates the approximate age of our forests and the corresponding stage of succession and development. The species composition can be moved back and structure can be moved back to an earlier stage of development (for example, to 20 years old) by way of natural disturbances and forest management (see the dark grey dashed clock hand pointing at 20). Species composition and structure can also move forward to a later stage (for example, 150 years old) by way of time, natural disturbances, and forest management that involves releasing shade-tolerant species and increasing structural complexity (as indicated by the light grey hand at 150).

Younger forests, or forests early in development have the highest rates of carbon sequestration, as this is when the amount of leaf area and the rate of photosynthesis peak during tree-to-tree competition. The higher rates occur when the forest is approximately 20-70 years old (comprised of trees 4"-16" in diameter), though the specific age and size depends on factors like site quality and land-use history. As overall forest growth slows down (often with canopy closure), as does carbon sequestration rates. This is where Connecticut's forests are now, 90-130 years of age. But trees continue to accumulate carbon at lesser rates, but increase the amount in which they can store carbon. Older or structurally complex forests comprised of mid- and shade tolerant trees store the most carbon. Both are sequestration and storage are important climate change mitigation factors.

David Property 2015, Lyme, CT | Lisa Whale

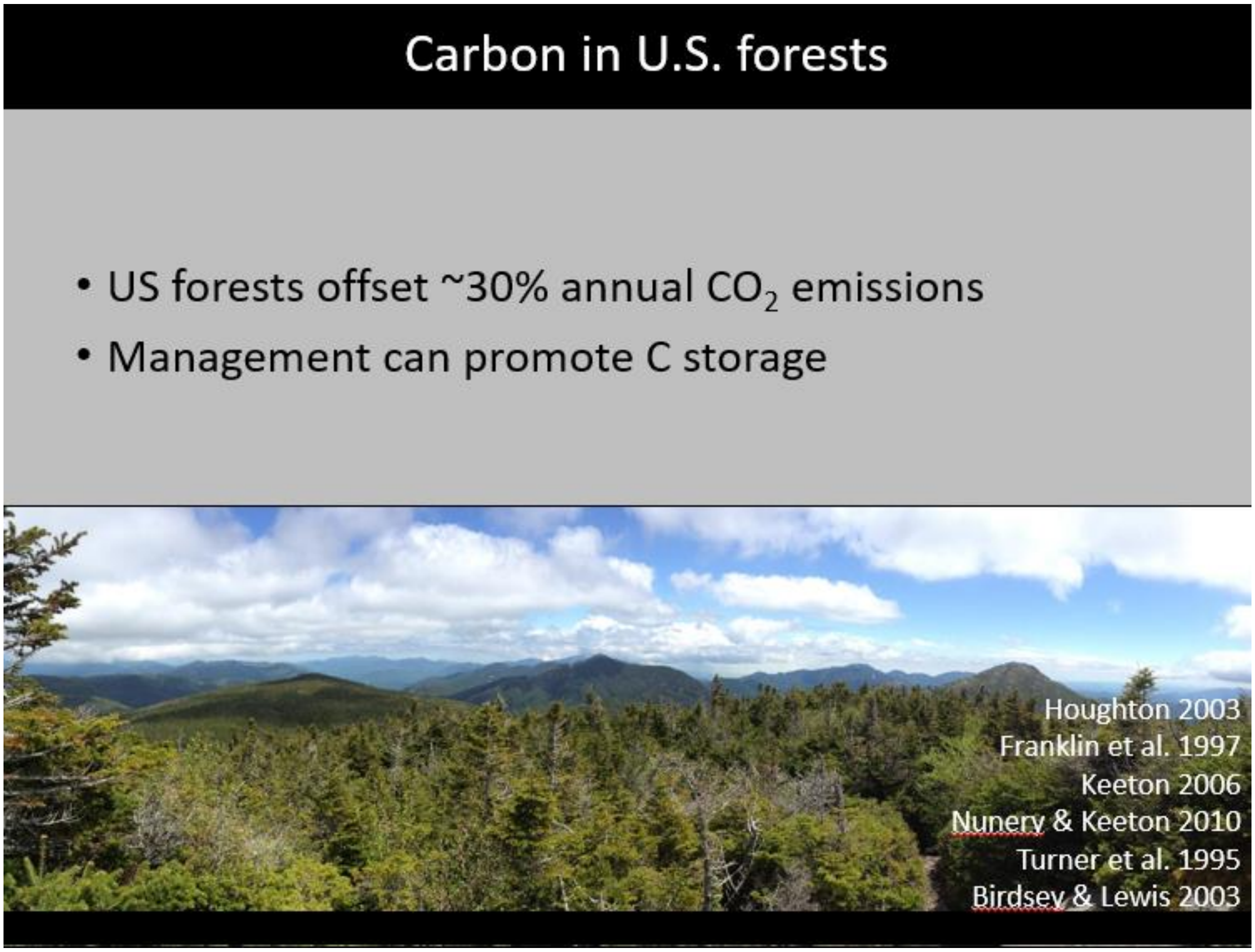
David Property 2019, Lyme, CT | Lisa Whale

Hamden, CT 2018| Tornado Damage

It is important to recognize that the forest might actually be a source of carbon immediately following a disturbance, as rates of tree growth, although rapid, are unable to counteract losses of carbon due to the decomposition of organic matter in the soil. This loss of carbon from decomposition is enhanced when large openings are created in the forest, which increases soil temperature and moisture availability and hence microbial activity.

It generally takes 10–15 years before there is enough forest growth to shift a disturbed area from a carbon source to a carbon sink.

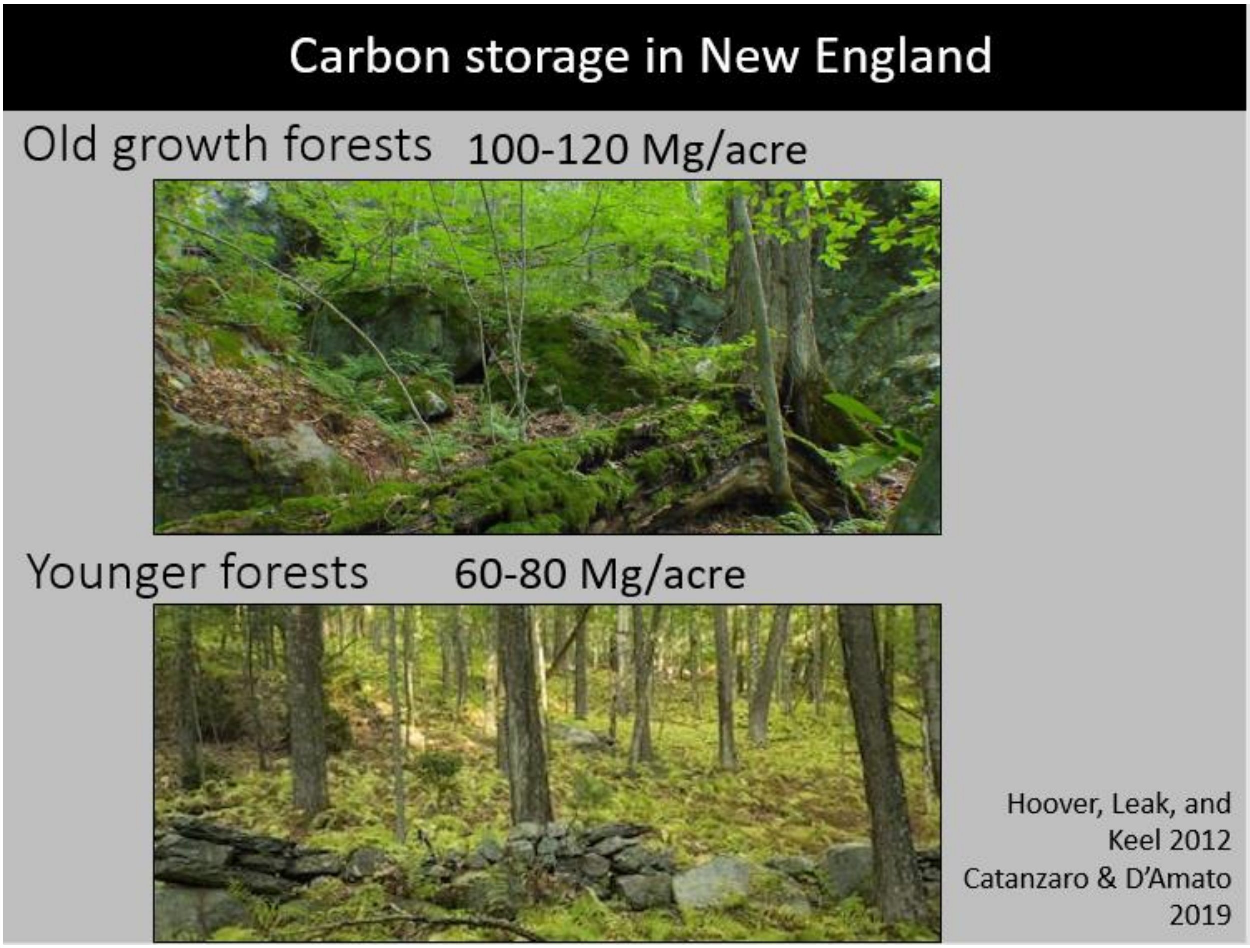
It would take significantly less time for forest carbon recovery, or no time at all, if the disturbance was sustainable forestry to remove forest products, depending on the forest products.



U.S. forests currently function as a carbon sink, offsetting about 30% if carbon dioxide emissions annually.

As mentioned earlier, our forests are maturing. Even though carbon uptake rates decline with forest maturity, complex forest structure can yield an increase or maintenance in net carbon sequestration (Nunery & Keeton 2010).

Influenced by type and intensity of management (Keeton 2006, Harmon et al. 2009, Nunery & Keeton 2010), aboveground carbon storage in northeastern secondary forests has the potential to double.

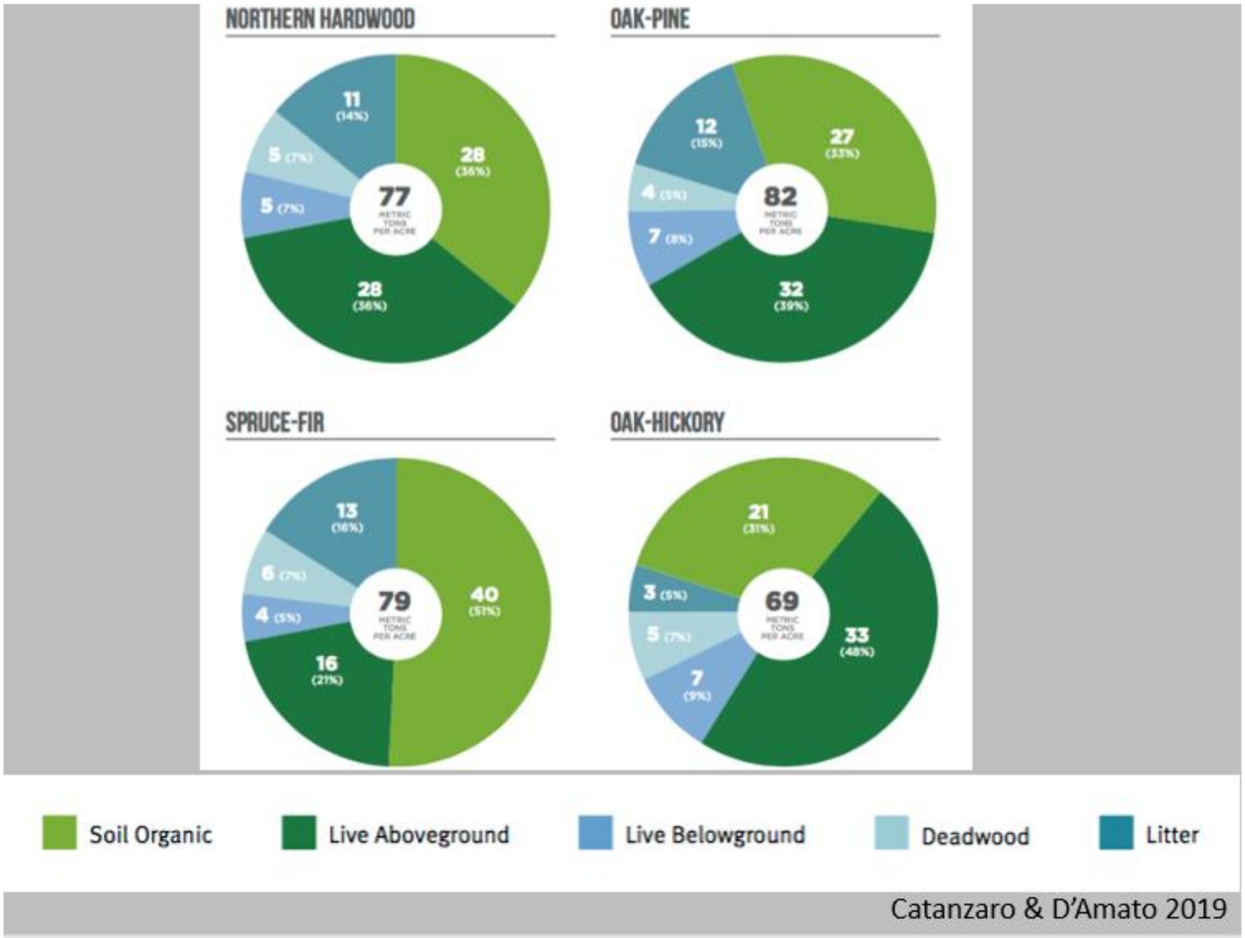


Estimates of the carbon stored in old growth forests range from 100 to 120 metric tons of carbon per acre (Hoover, Leak, and Keel 2012).

Due to our land-use history, our current forests are relatively young (recall, many are 100 years old) and generally store 60–80 metric tons of carbon per acre.

Future gains in forest carbon will primarily come from the diameter growth of trees, additions to the deadwood pool from dying trees, and the accumulation of soil organic carbon from root growth and decomposition

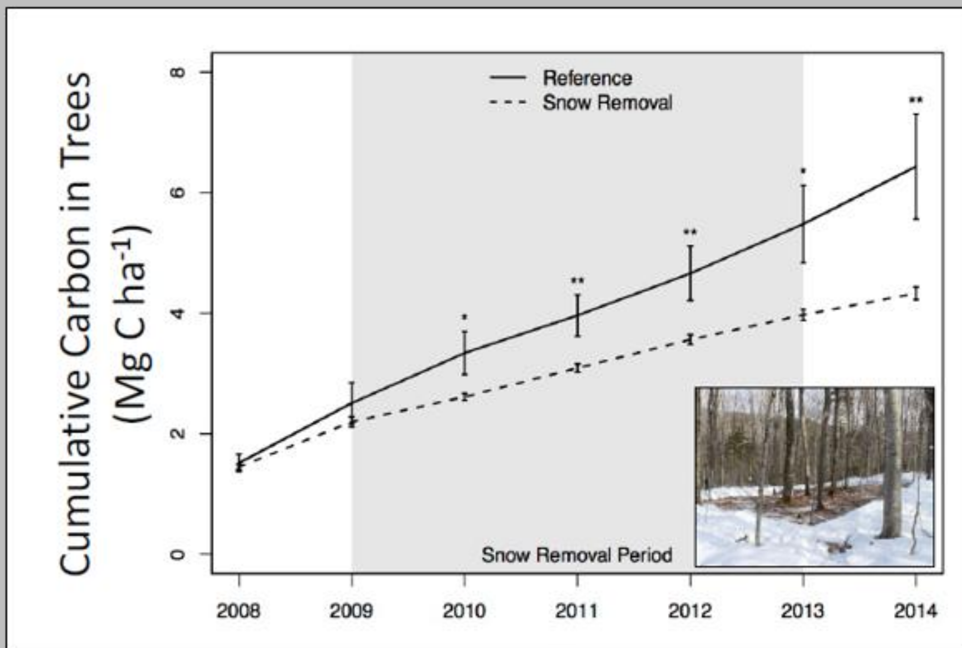
It's also worth noting that multi Aged Forests can balance sequestration and storage.



These data are gathered from USFS 2018 and are based on 80-100 year old New England forest types. Carbon is in metric tons per acre.

Connecticut's forested landscape is comprised mostly of oak-hickory forests. Roughly, these forests store about 70 metric tons of carbon per acre. Almost 50% of which is stored in live aboveground biomass. At this time, live aboveground and soil pools store the most amount of carbon in all forest cover types. As mentioned previously, over time the dead aboveground (deadwood) pool will play a great role in Connecticut's carbon storage. It will remain important to maintain deadwood on the landscape.

Observing a reduction in sequestration & storage

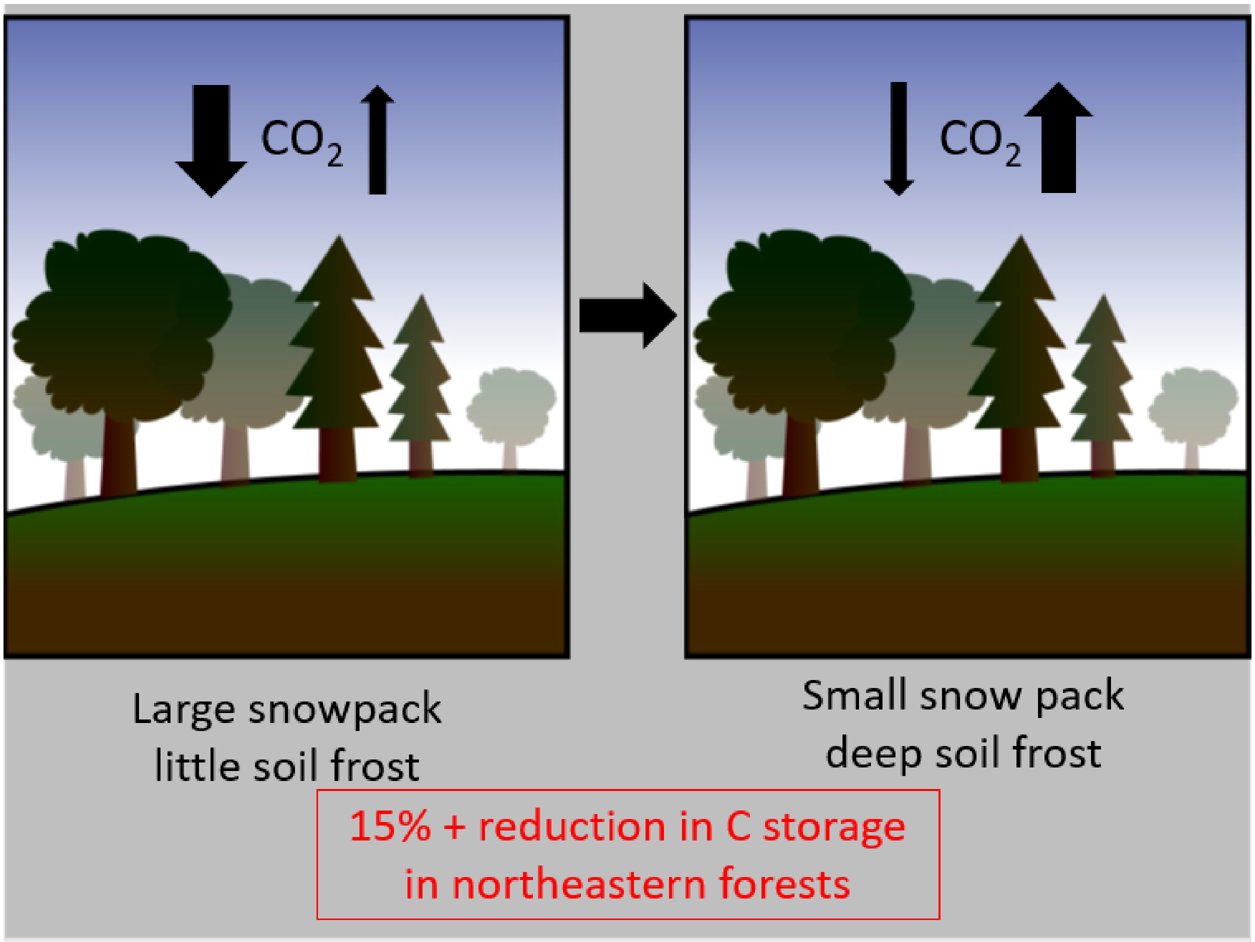


Pamela Templer, Ph.D., Boston University
Templer et al. 2012

So we've just reviewed the fundamental principles of forest carbon accumulation dynamics. I am now just introducing some of the nuances to these dynamics, which we continue to learn over time.

Current research suggests a compromised ability for northeastern trees/forests to sequester and store carbon in a warming climate. This study (Templer et al. 2012) conducted at Harvard Forest, suggests that a lack of winter snow cover, as recently observed and is expected to continue, reduces carbon storage by way of soil respiration.

In this figure you see total carbon (Mg/hectare) over time. The solid line represents carbon storage in reference plots (forested areas where snow was allowed to accumulate) and the dotted line represents forested areas where snow was physically removed. Total carbon stored in forests without snow cover is less than that with snow cover.



Looked at differently, what is being observed that without snow covering the forest floor, soil is more susceptible to frost, damaging tree roots. In previous climatic conditions, when our forests consistently had winter snowpack and little soil frost (left image), they functioned in a way that could retain most of the carbon being removed from the atmosphere. Now, with less snowpack and more soil frost, they are unable to function as well. This is resulting in a greater than 15% reduction in carbon storage in northeastern forests (Templer et al. 2012).

Now I certainly don't mean to end on a negative note – but with my limited time remaining, I want to shed light on the fact that we are always learning more with time and opportunities. It is important to stay informed.

To learn more, please contact me, or tap into some of these other resources. I also recommend visiting the USFS Northern Institute of Applied Climate Science's Climate Change Response Framework: https://forestadaptation.org/.