



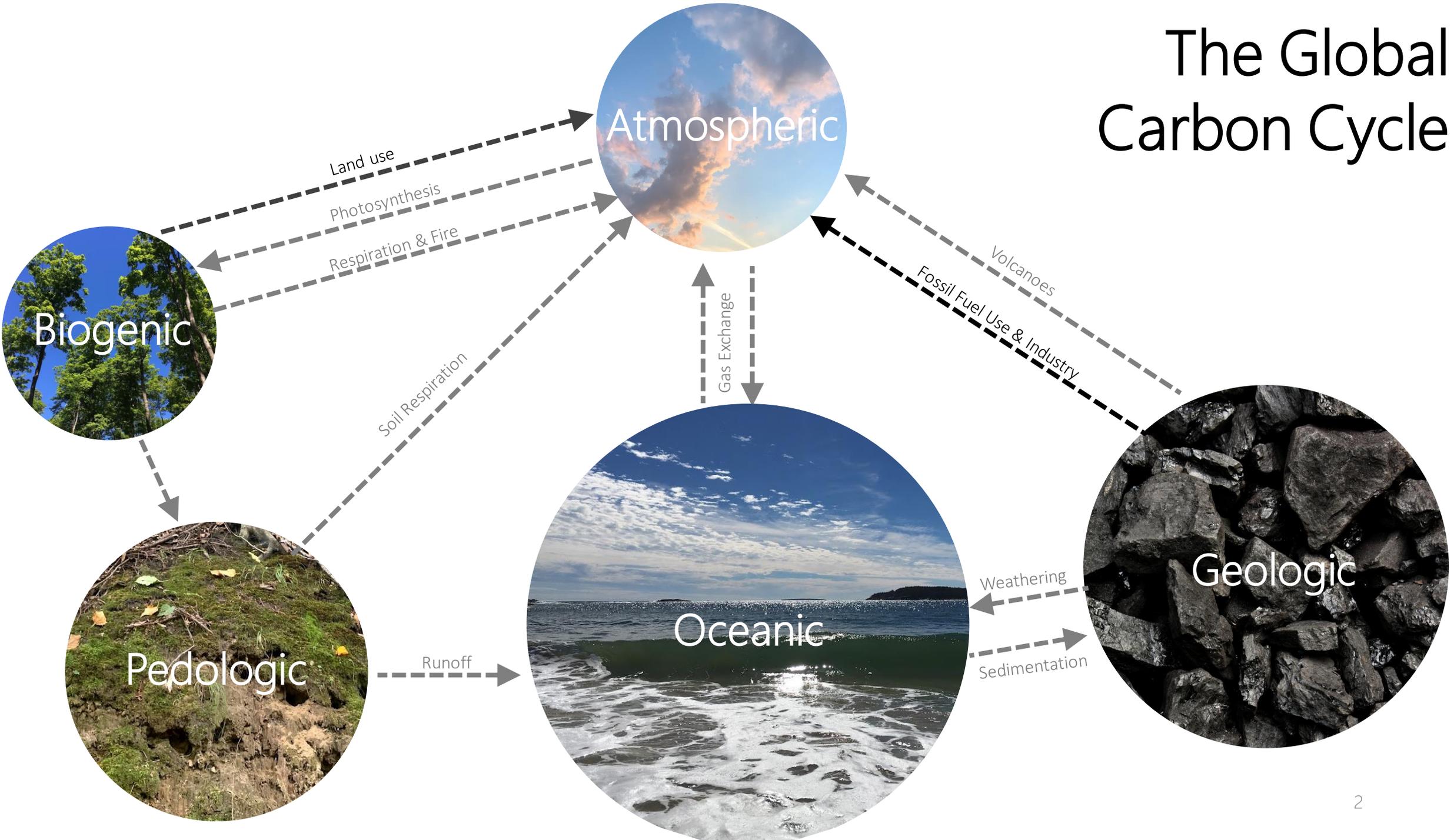
# Vermont's Forests: Carbon and Climate Change

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Climate Forester | Forests, Parks and Recreation

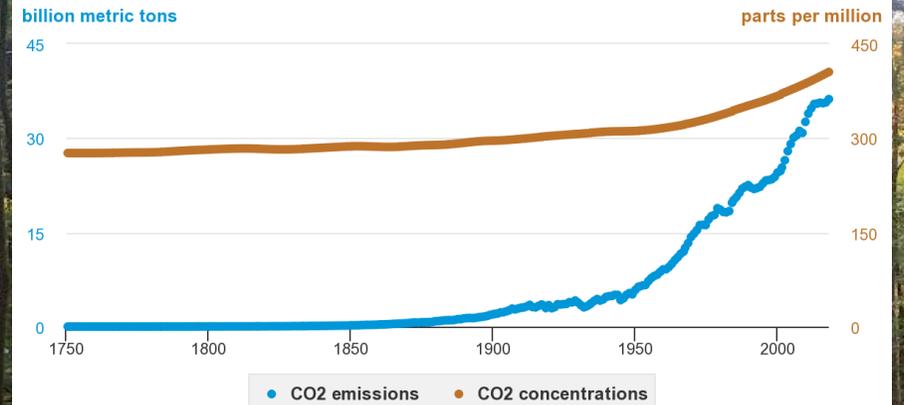


# The Global Carbon Cycle



Carbon released to the atmosphere has an affinity to form carbon dioxide (CO<sub>2</sub>) which is a powerful greenhouse gas, trapping the Earth's energy

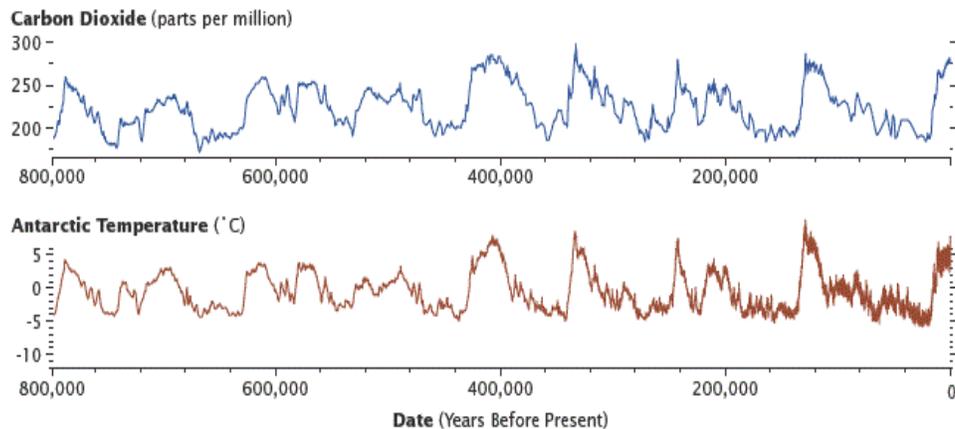
World carbon dioxide (CO<sub>2</sub>) emissions from fossil fuel combustion and global atmospheric concentrations CO<sub>2</sub> (1751-2018)



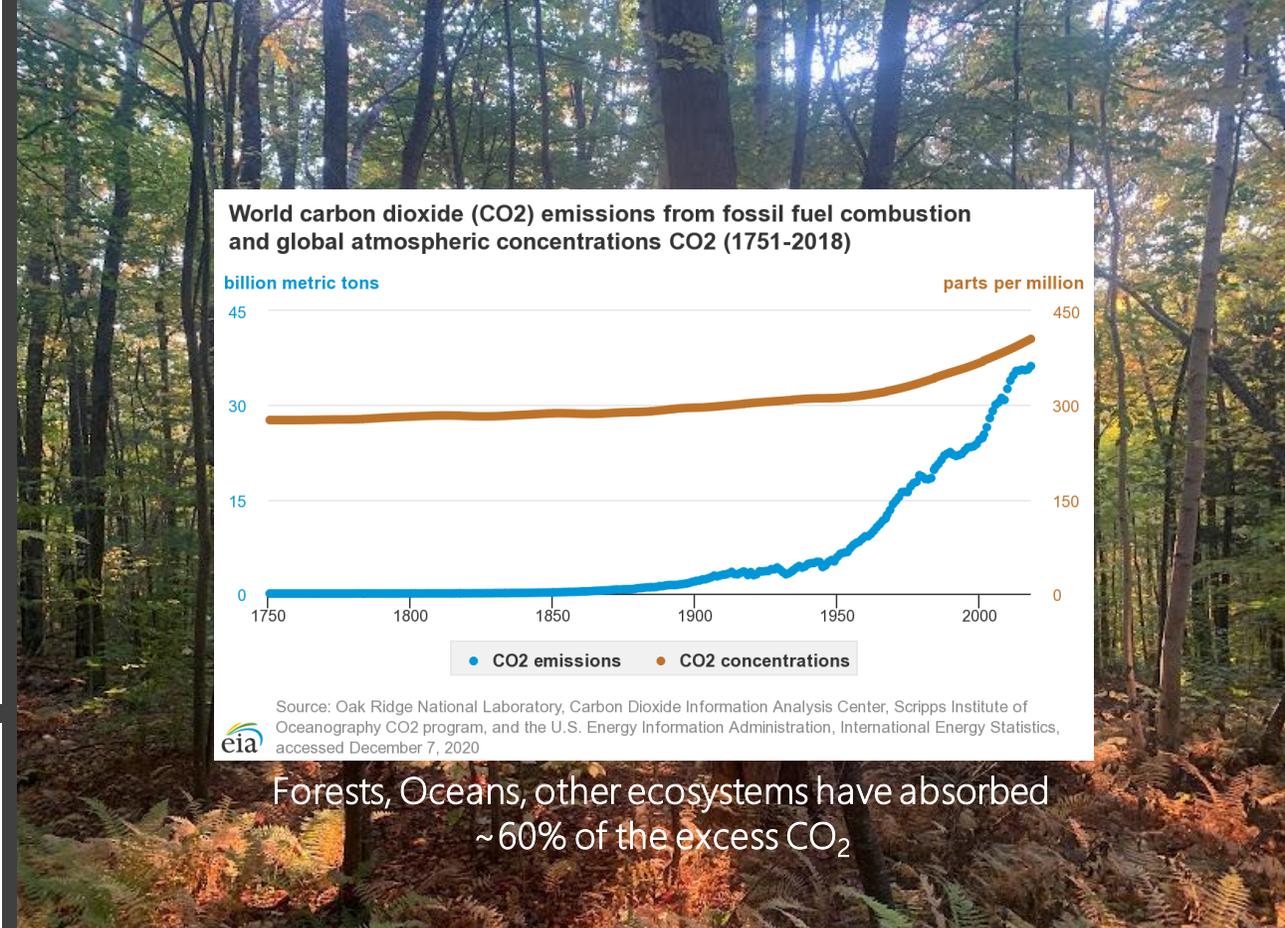
Source: Oak Ridge National Laboratory, Carbon Dioxide Information Analysis Center, Scripps Institute of Oceanography CO<sub>2</sub> program, and the U.S. Energy Information Administration, International Energy Statistics, accessed December 7, 2020

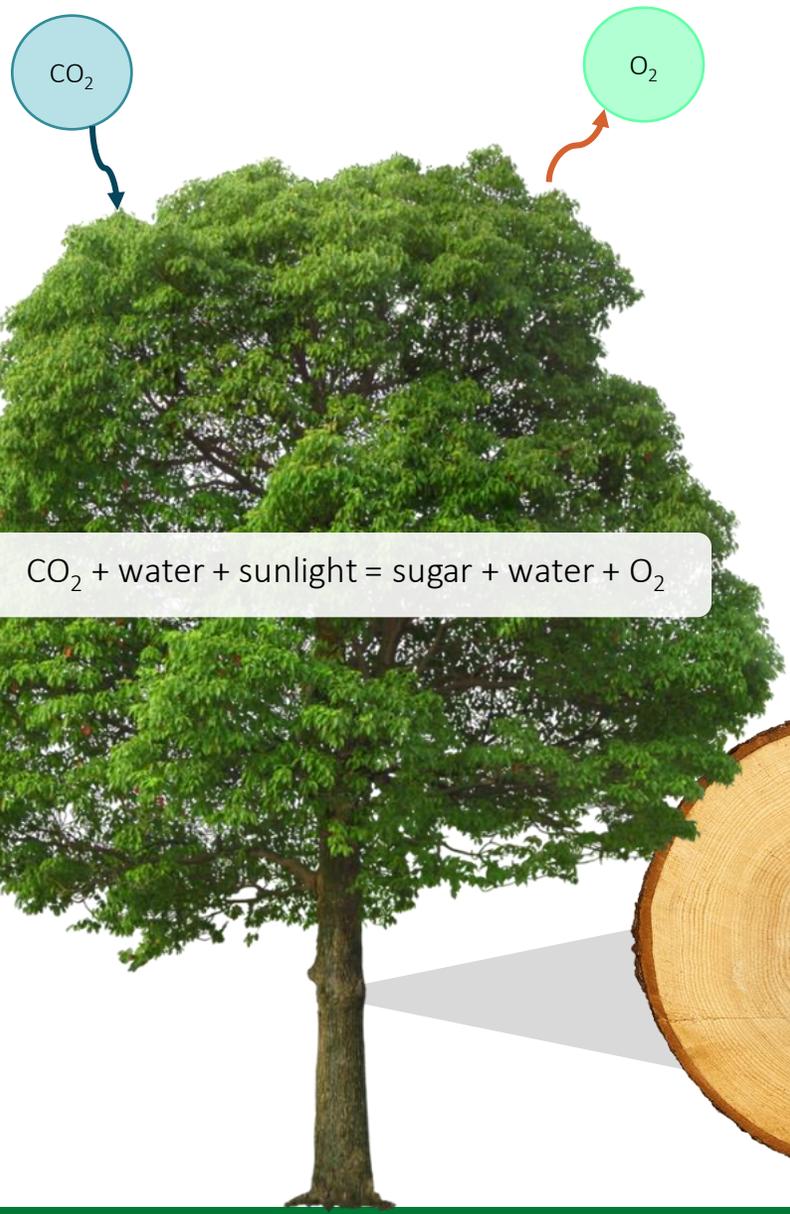
Forests, Oceans, other ecosystems have absorbed ~60% of the excess CO<sub>2</sub>

Atmospheric CO<sub>2</sub> concentrations are directly tied to global temperatures



Source: <https://www.feedbackreigns.net/evidence/temperature-co2/>



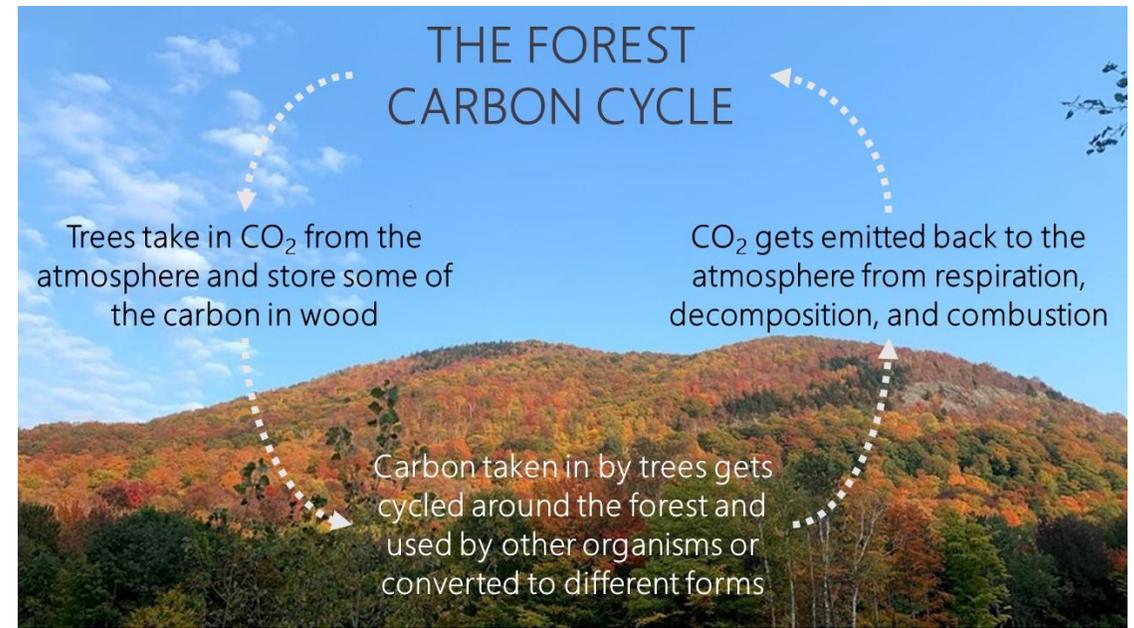


CO<sub>2</sub> + water + sunlight = sugar + water + O<sub>2</sub>



**HALF**  
of the dry weight of wood is carbon that was removed from the atmosphere by the growing tree

Trees can help mitigate climate change by sequestering CO<sub>2</sub> from the atmosphere and storing the carbon in wood



### THE FOREST CARBON CYCLE

Trees take in CO<sub>2</sub> from the atmosphere and store some of the carbon in wood

CO<sub>2</sub> gets emitted back to the atmosphere from respiration, decomposition, and combustion

Carbon taken in by trees gets cycled around the forest and used by other organisms or converted to different forms

# Quick Carbon Terminology Primer

## Carbon storage

total the amount of carbon in an entity (tree, acre of forest, cord of wood)

## Carbon sequestration

the process of taking CO<sub>2</sub> from the atmosphere and storing it

## Carbon emissions

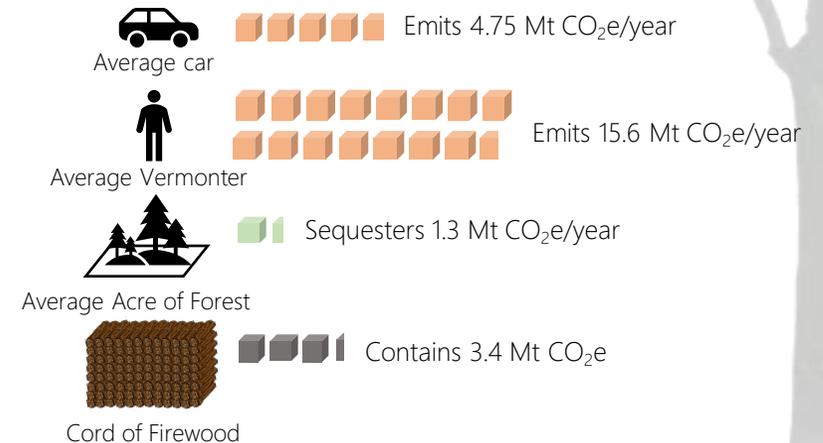
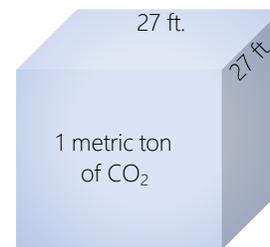
the opposite of sequestration (CO<sub>2</sub> release back to atmosphere)

## Carbon sequestration + carbon emissions = carbon flux

the change in carbon storage

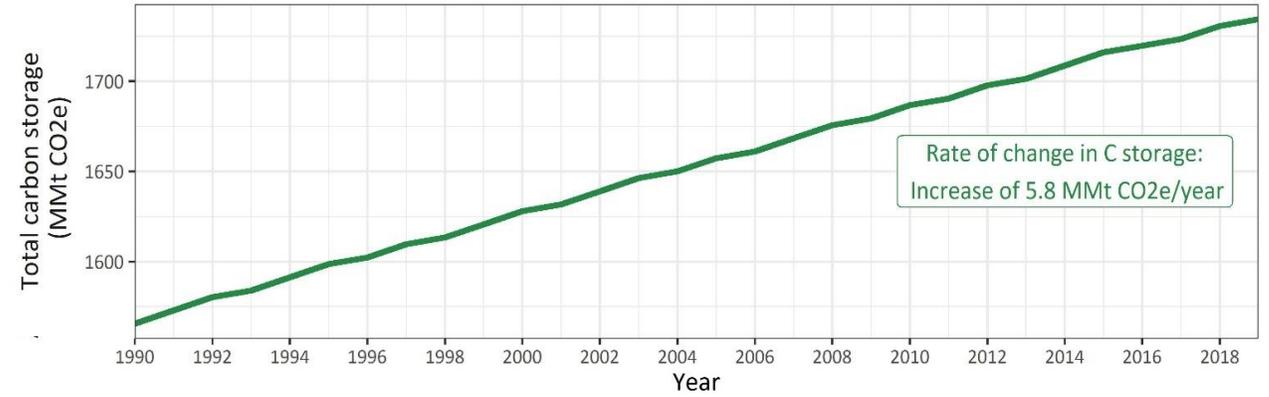
- Negative values = sequestration
- Positive values = emissions

For easier comparisons, we convert carbon and other greenhouse gases to the same units = **carbon dioxide equivalent (CO<sub>2</sub>e)**

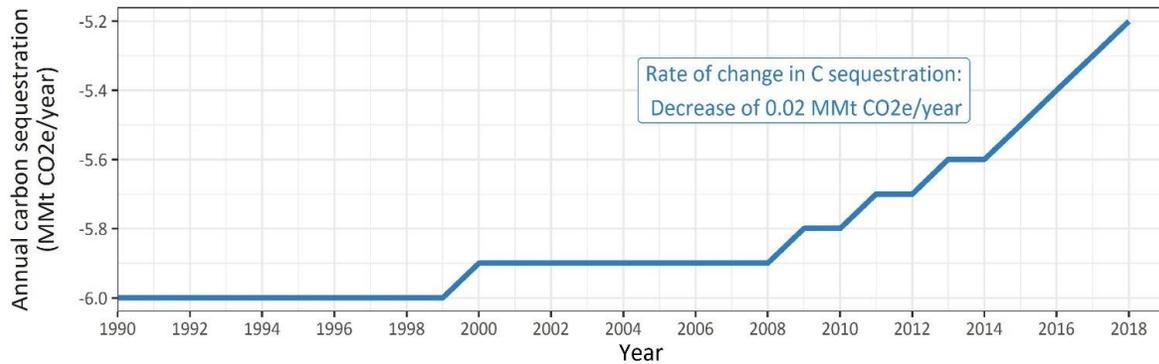




VT's 4.5 M acres of forest are a net carbon sink

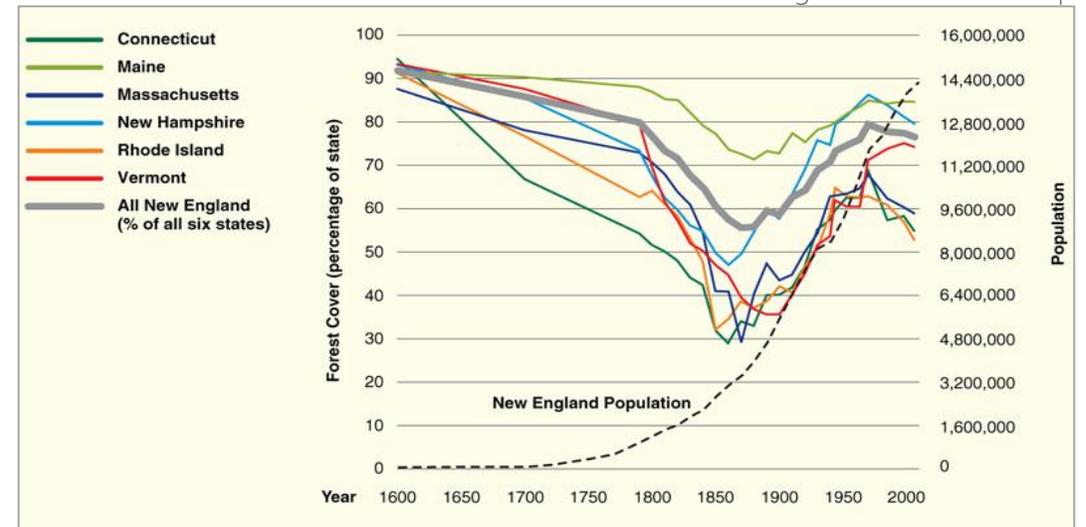


But the rate of sequestration is declining

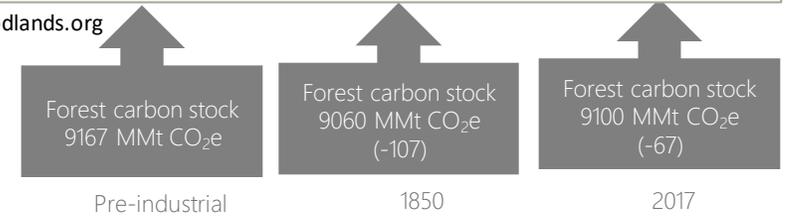


Forest loss = net carbon emissions

Forest gain = net carbon sequestration

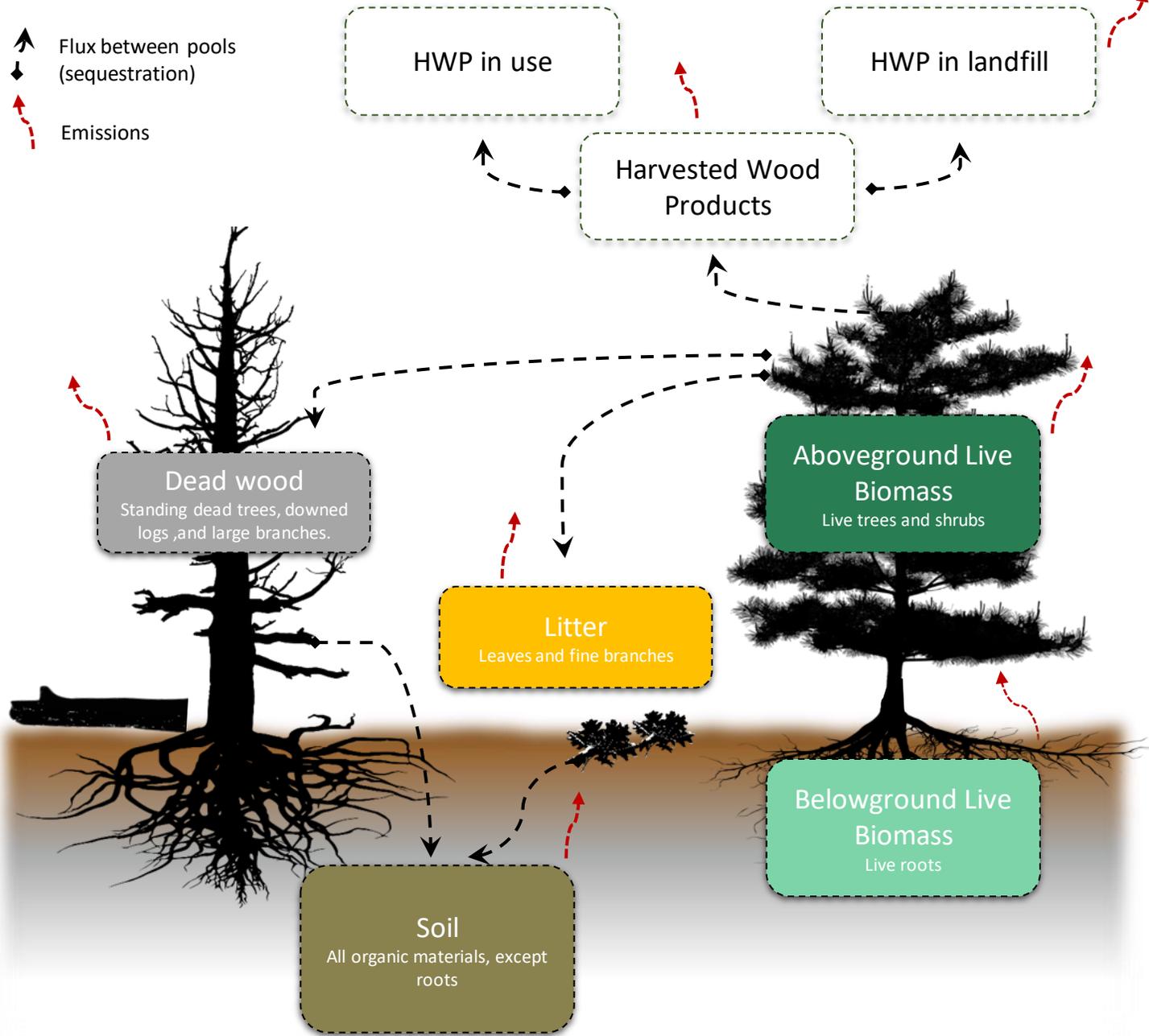
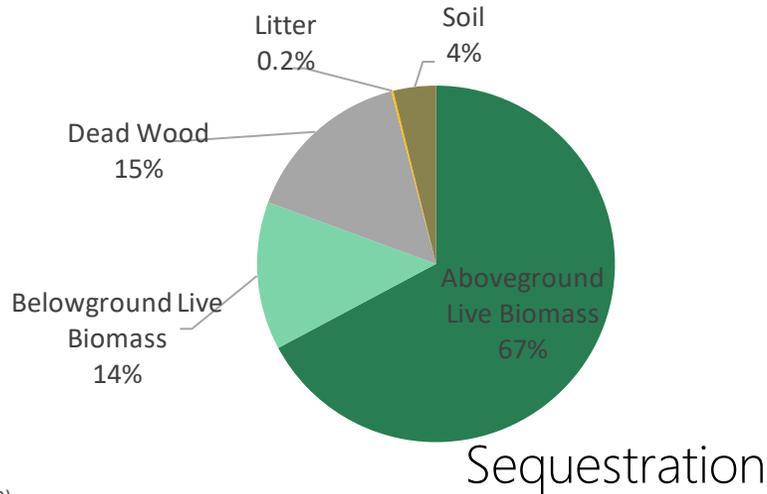
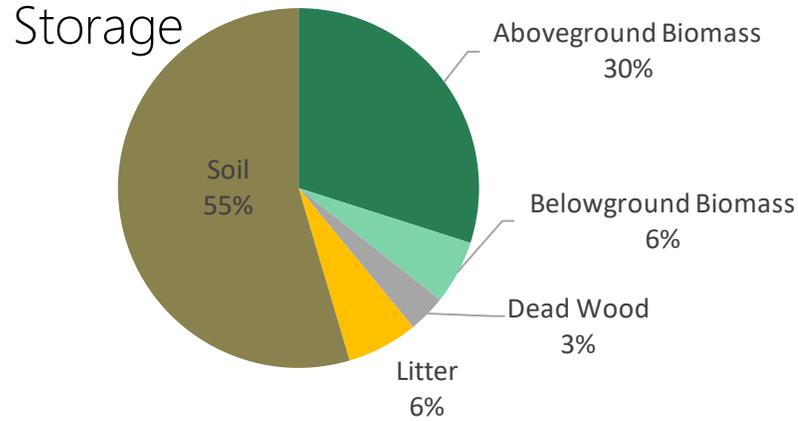


Source: Wildlands and Woodlands.org



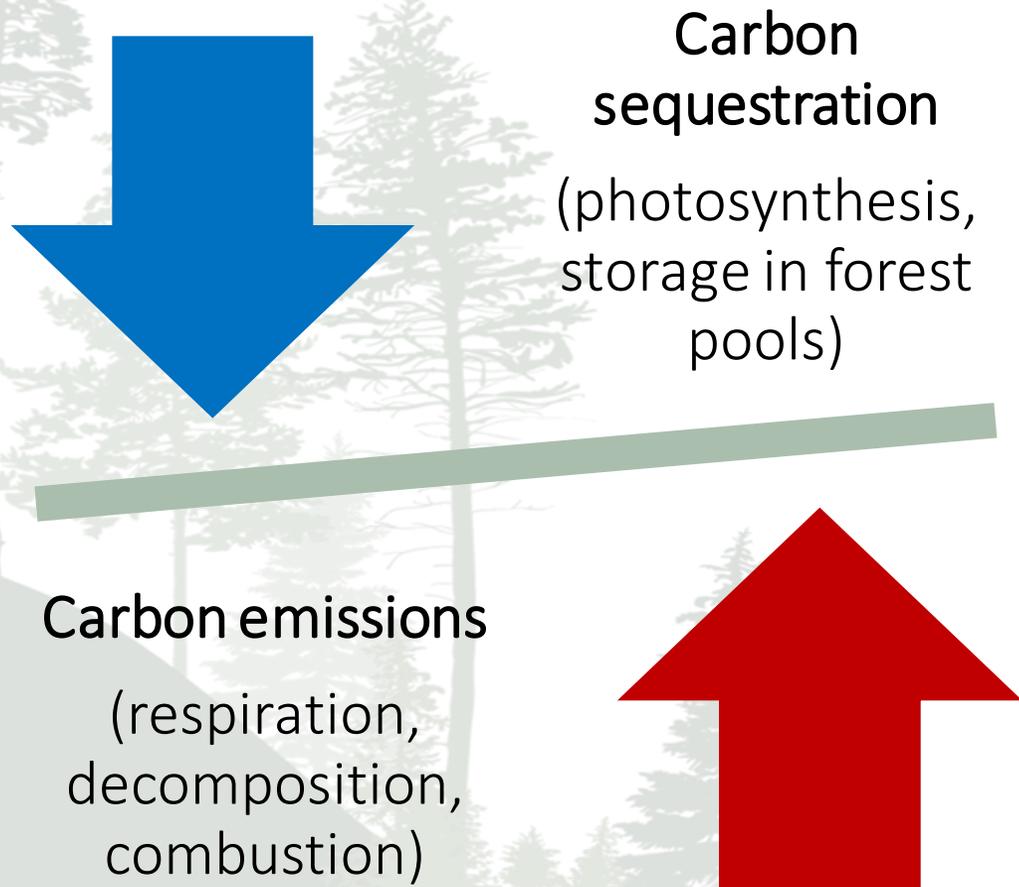
Still have not fully recovered to pre-Industrial levels

# Forest carbon pools



Data source: Domke et al. (2020)

# Mitigation potential of forests depends on the balance between uptake and release



## CLIMATE FACTORS

- Temperature and precipitation
- Length of growing season

## SITE FACTORS

- Nutrient, light, water
- Soil
- Disturbances, insects/disease
- Tree density, size

## TREE FACTORS

- Species, age
- Stress

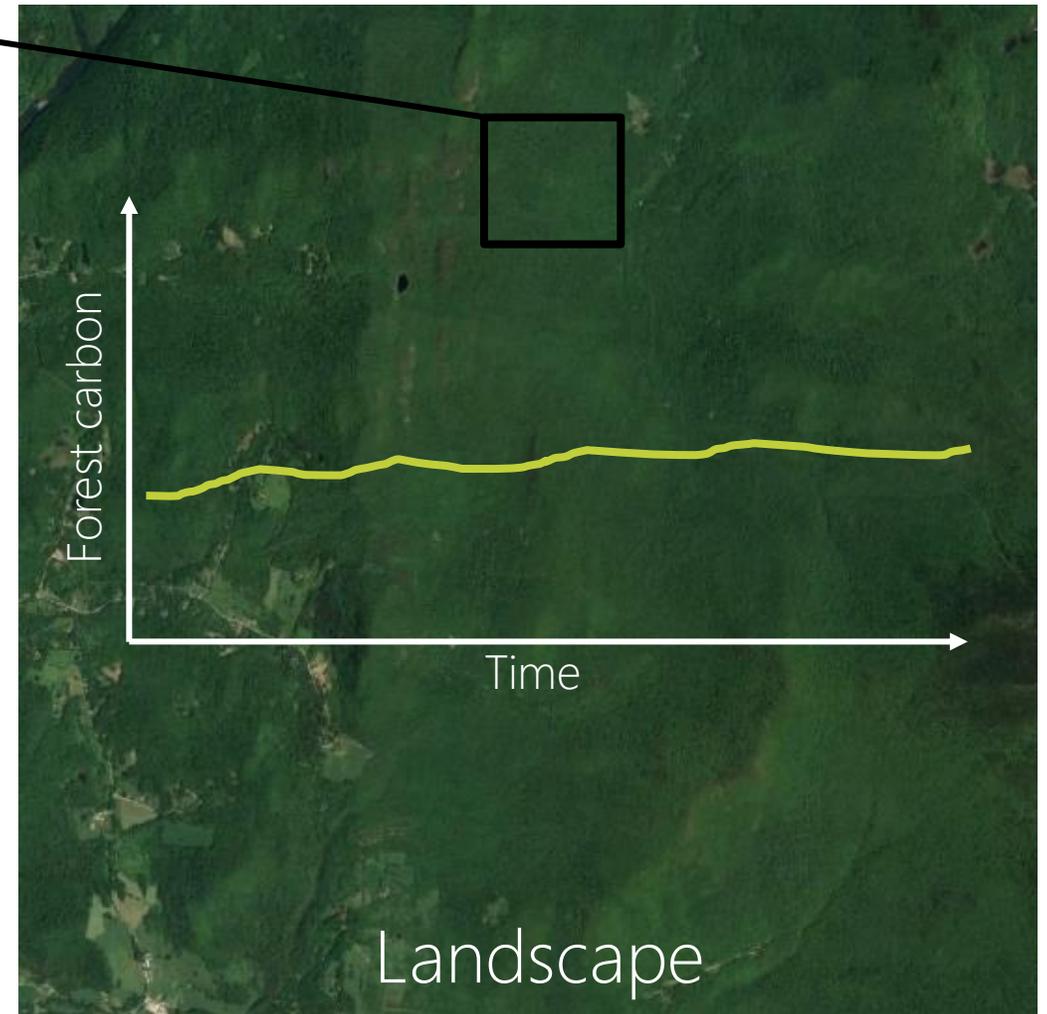
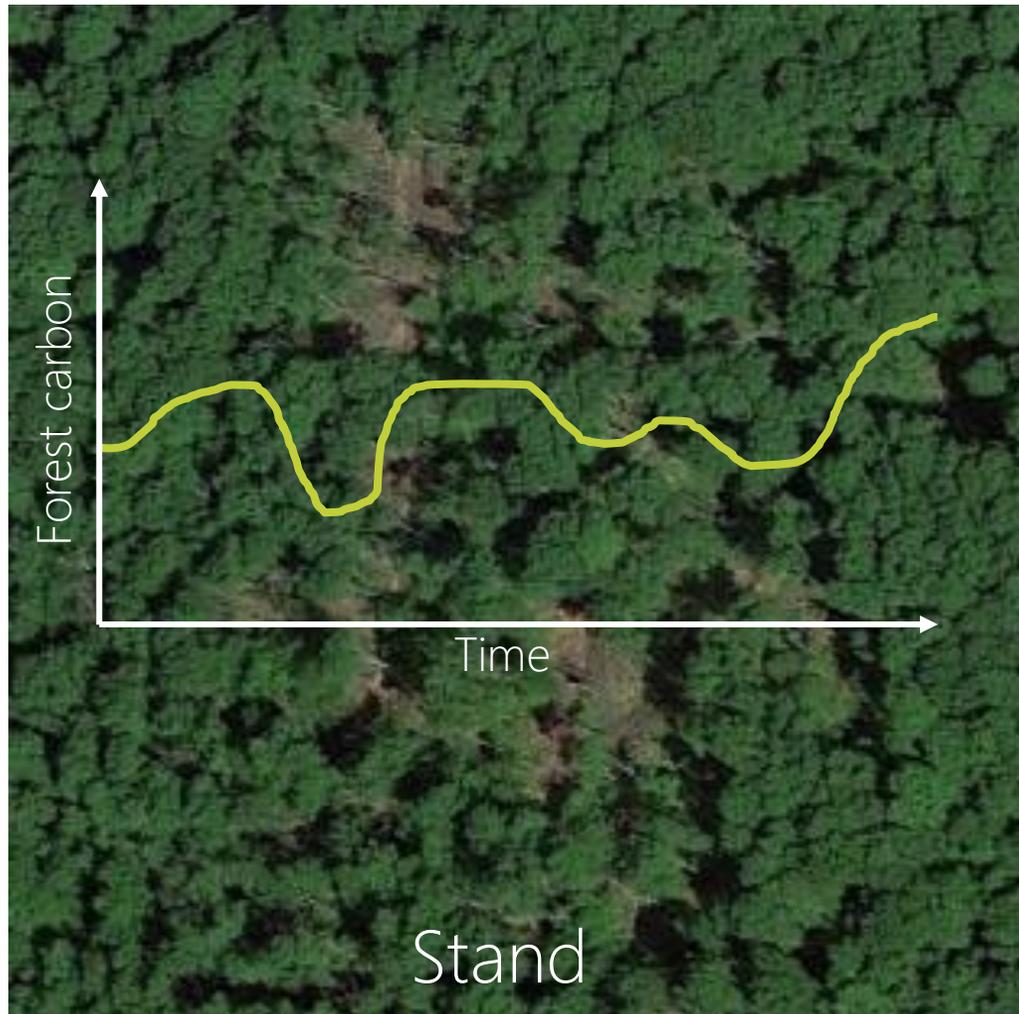


Not all forest stands are carbon sinks

Carbon sink  
Sequestration > Emissions

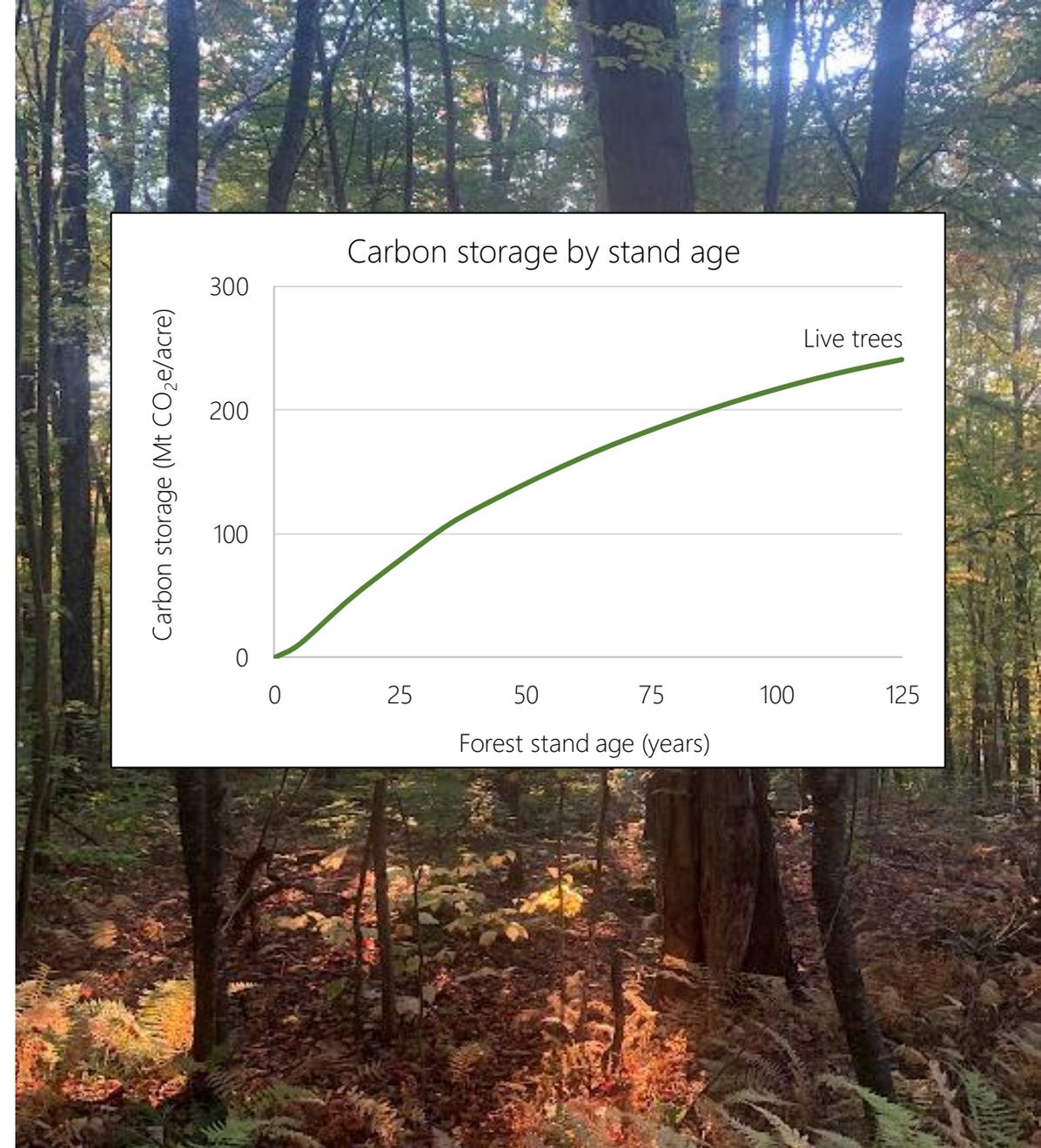
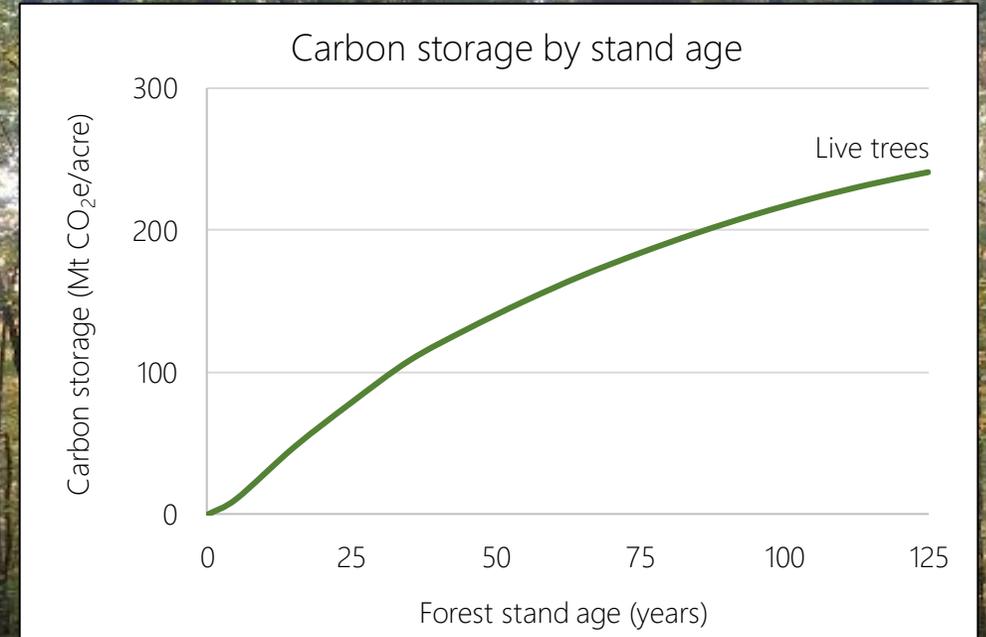
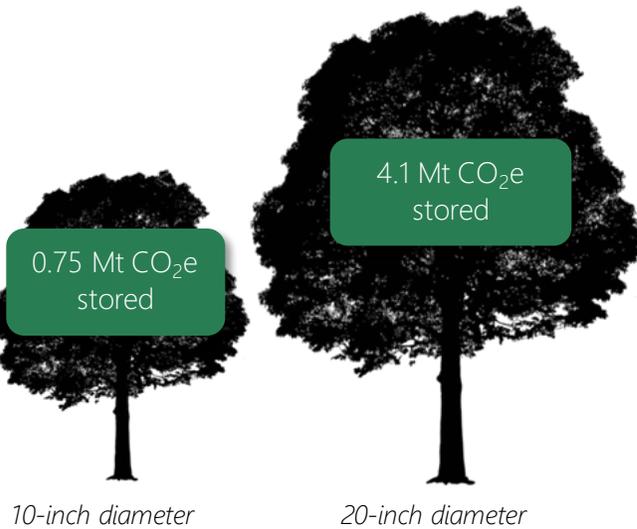
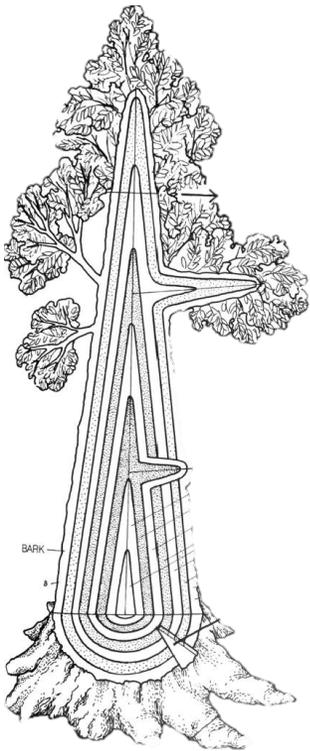
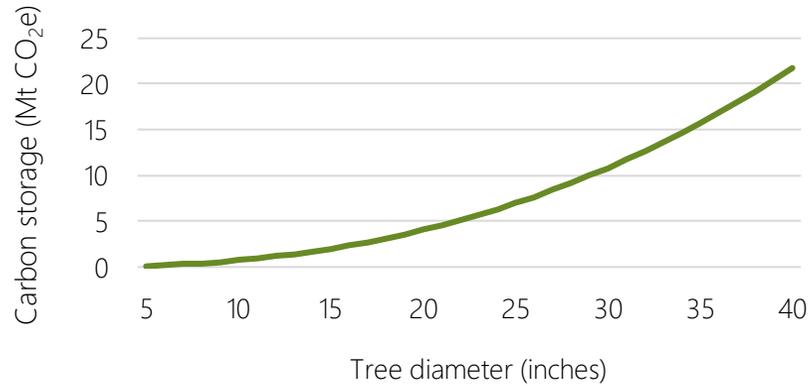
Carbon source  
Sequestration < Emissions

# Forest carbon dynamics depend on the spatial and temporal scale



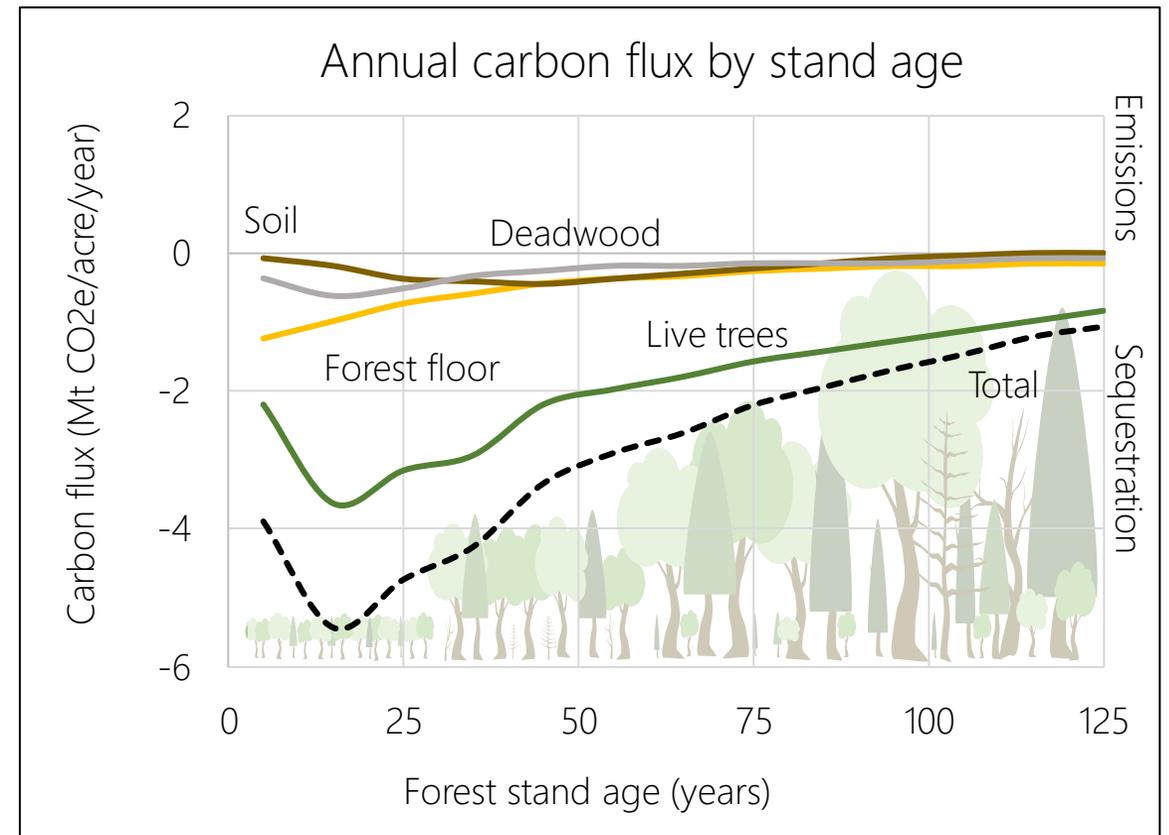
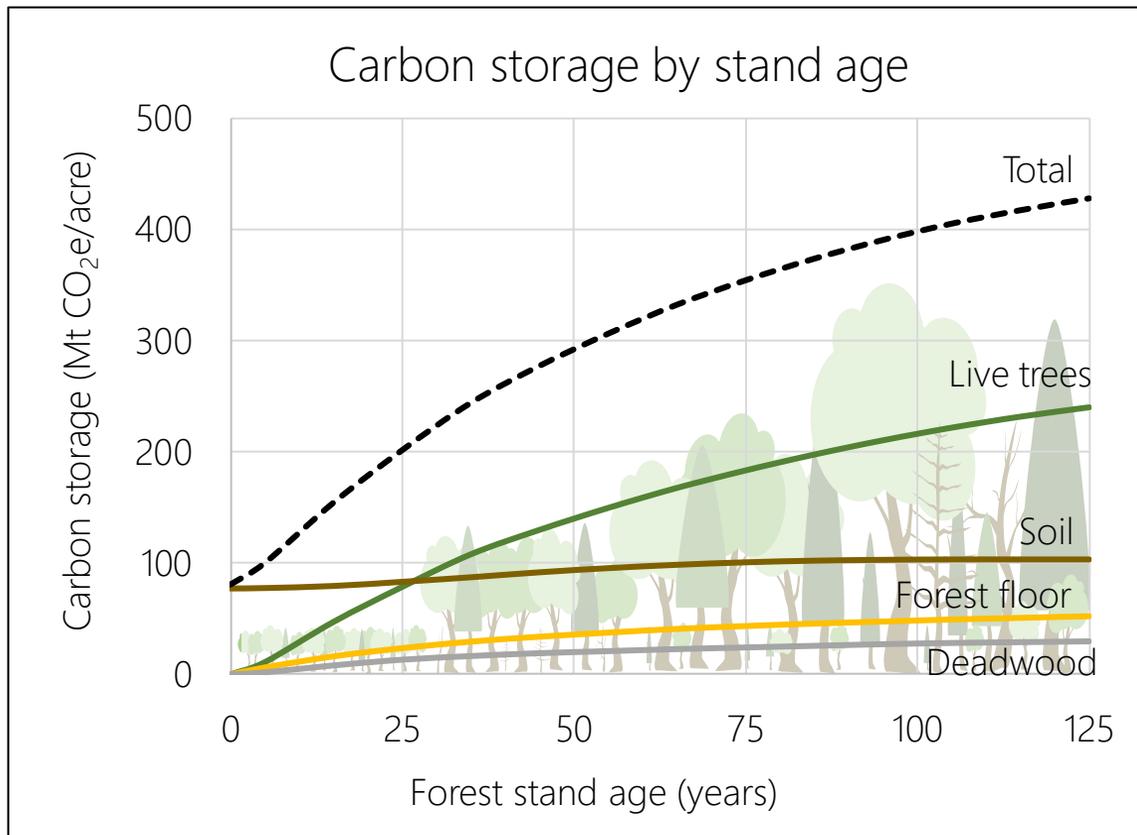
# Carbon in a tree vs. forest

Carbon in a sugar maple tree at different diameters



# Carbon storage and carbon sequestration peak at different life stages

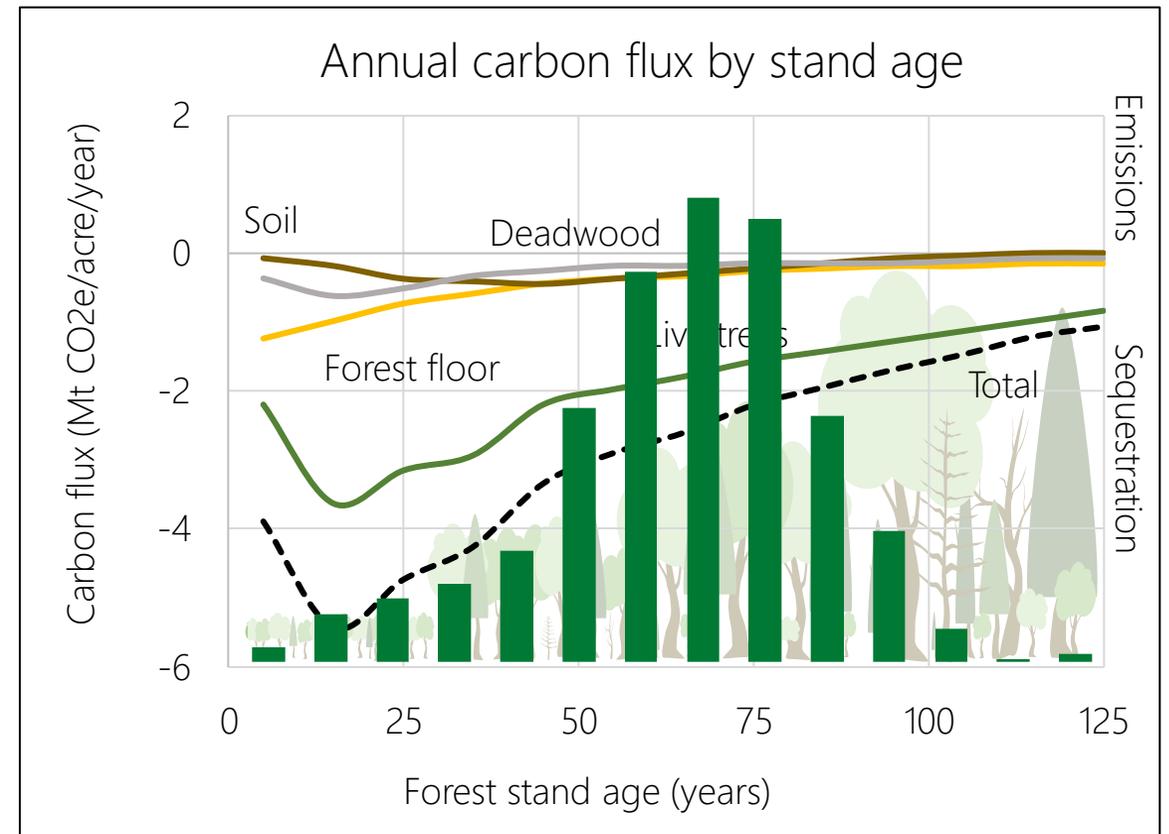
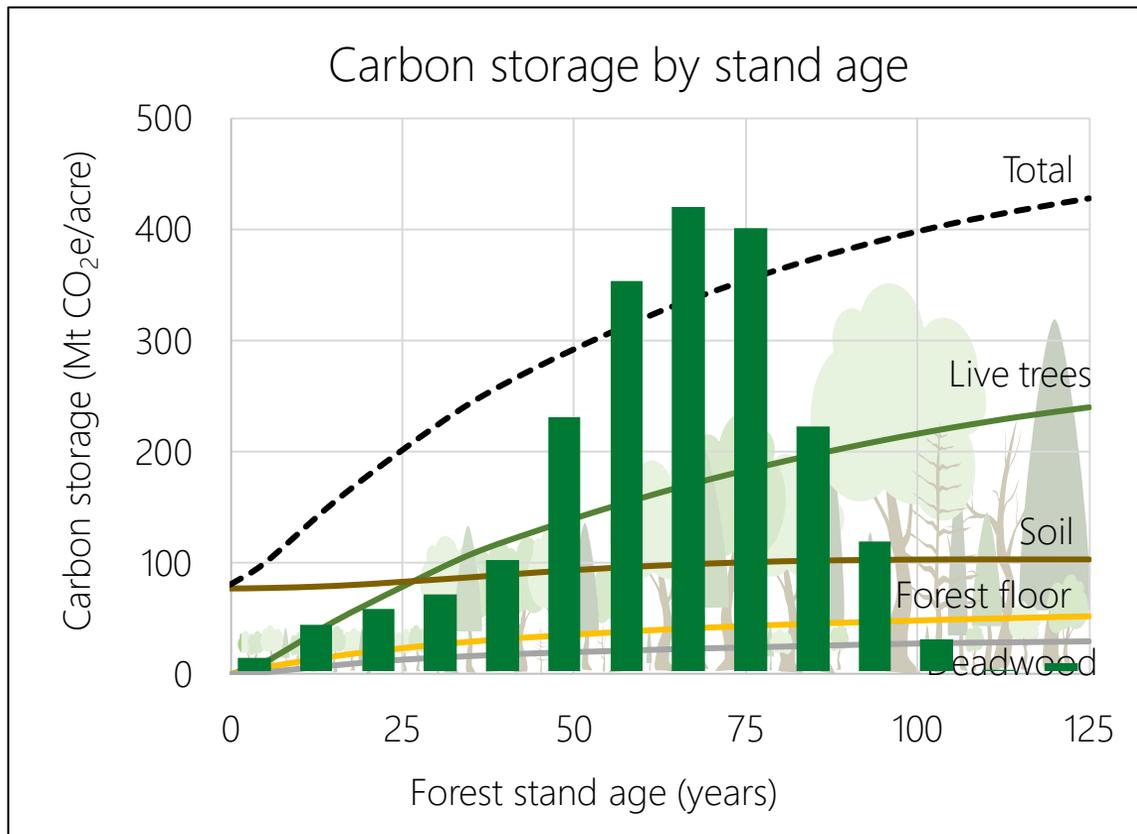
Take home message: stand age diversity across the landscape is key



Data source: Smith et al. 2006 - carbon stocks and fluxes following afforestation for maple-beech-birch forest

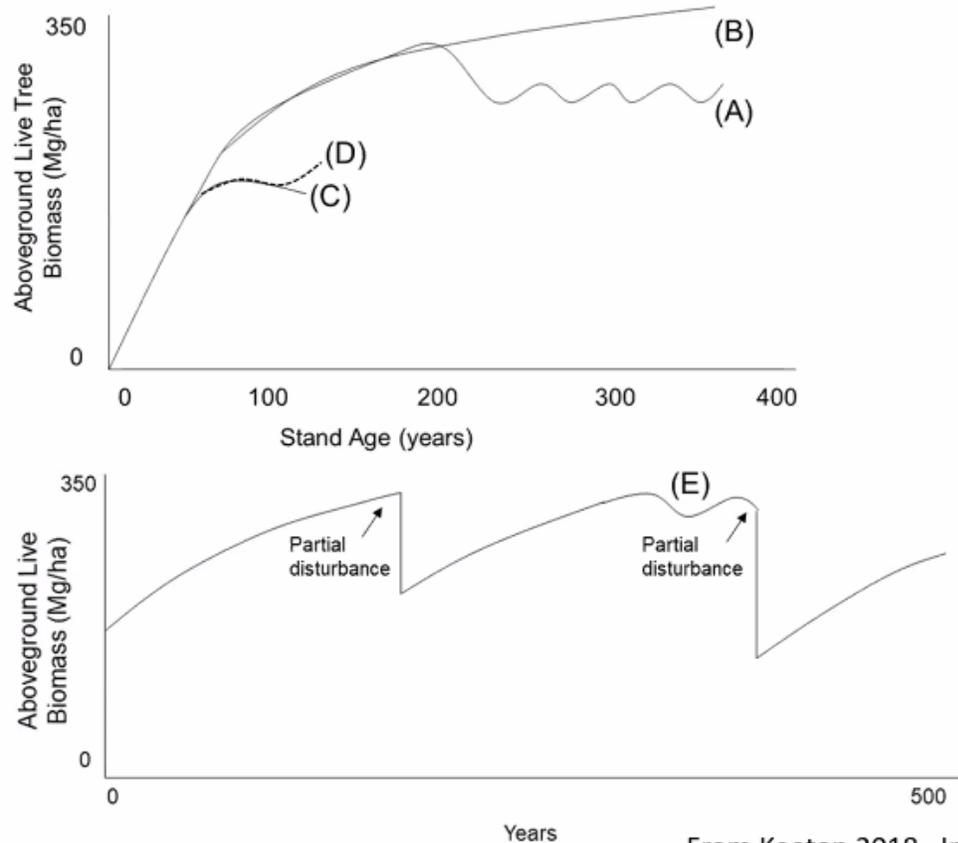
# Carbon storage and carbon sequestration peak at different life stages

Take home message: stand age diversity across the landscape is key



Data source: Smith et al. 2006 - carbon stocks and fluxes following afforestation for maple-beech-birch forest

# While older forests on average store more carbon, there are many trajectories that a forest can follow



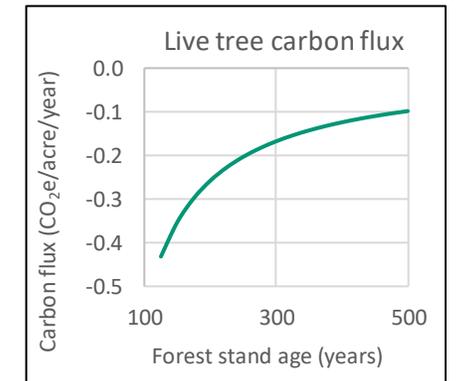
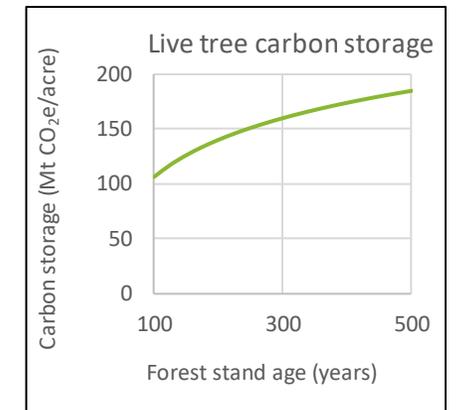
From Keeton 2018. In: Barton and Keeton, Island Press

Depends on

- Tree species
- Site quality
- Past land use
- Disturbance events
- Stressors
- Pests and pathogens
- Climate

## Carbon Data from Old Forests in New England

Data source: Keeton et al. 2011





## How does forest management affect forest carbon?

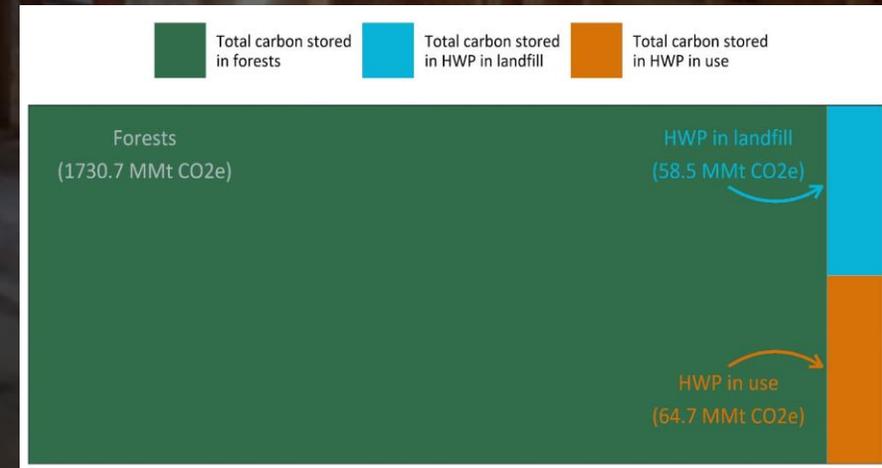
- Harvests reduce forest carbon stocks of the stand because there is a removal of some amount of carbon (wood)
- Soils are typically not impacted much except by equipment
- an cycle carbon to other pools, may result in positive fluxes due to high amounts of deadwood and decay
- Can result in more rapid carbon sequestration as new trees grow up
- High variability depending on site, silvicultural systems, equipment, retention, time of year
- When considering impacts of management, we must consider LEAKAGE

Harvested wood products store carbon for as long as they are in use

**Carbon storage** for as long as product is in use, and when it is no longer in use and is in a landfill slowly decomposing.

Can provide additional CO<sub>2</sub> reduction benefits by acting as a **substitute** for high GHG products (steel, concrete, plastics, fossil fuels)

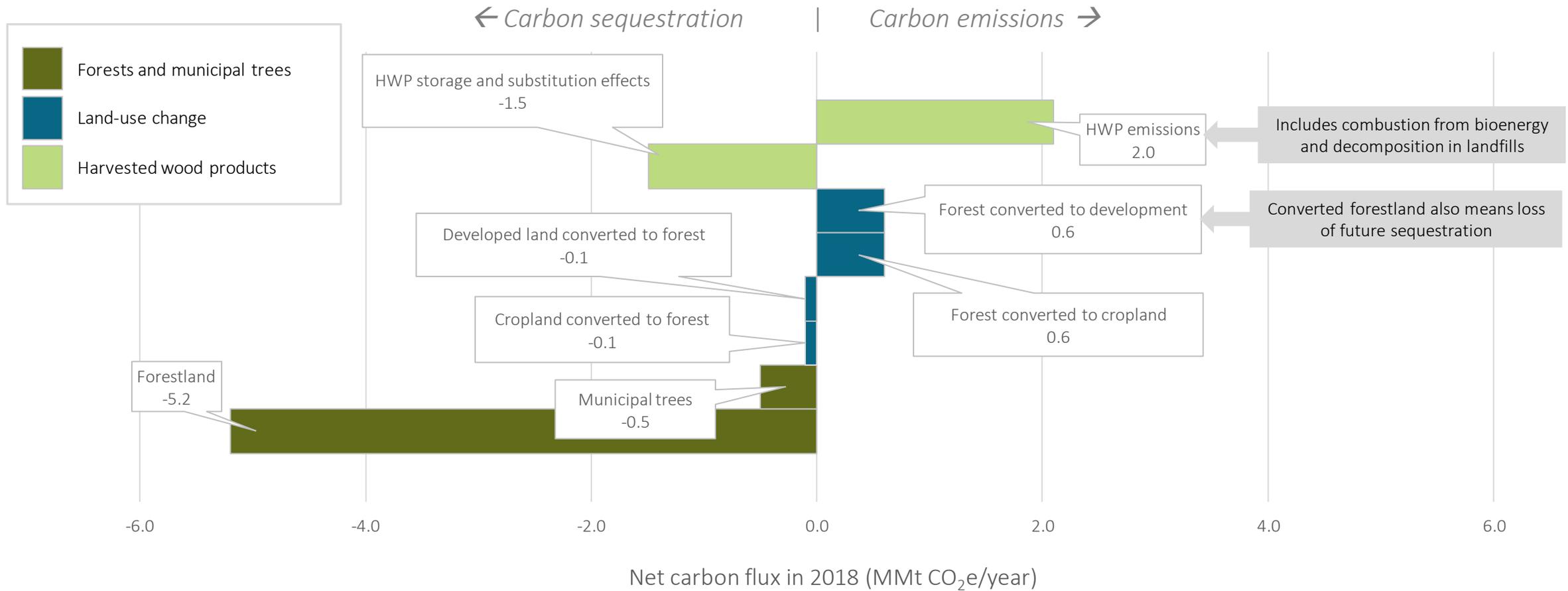
HWP contribute 7% to total carbon storage of the VT forest sector



Data source: Domke et al. (2020) and Dugan et al. (2021)

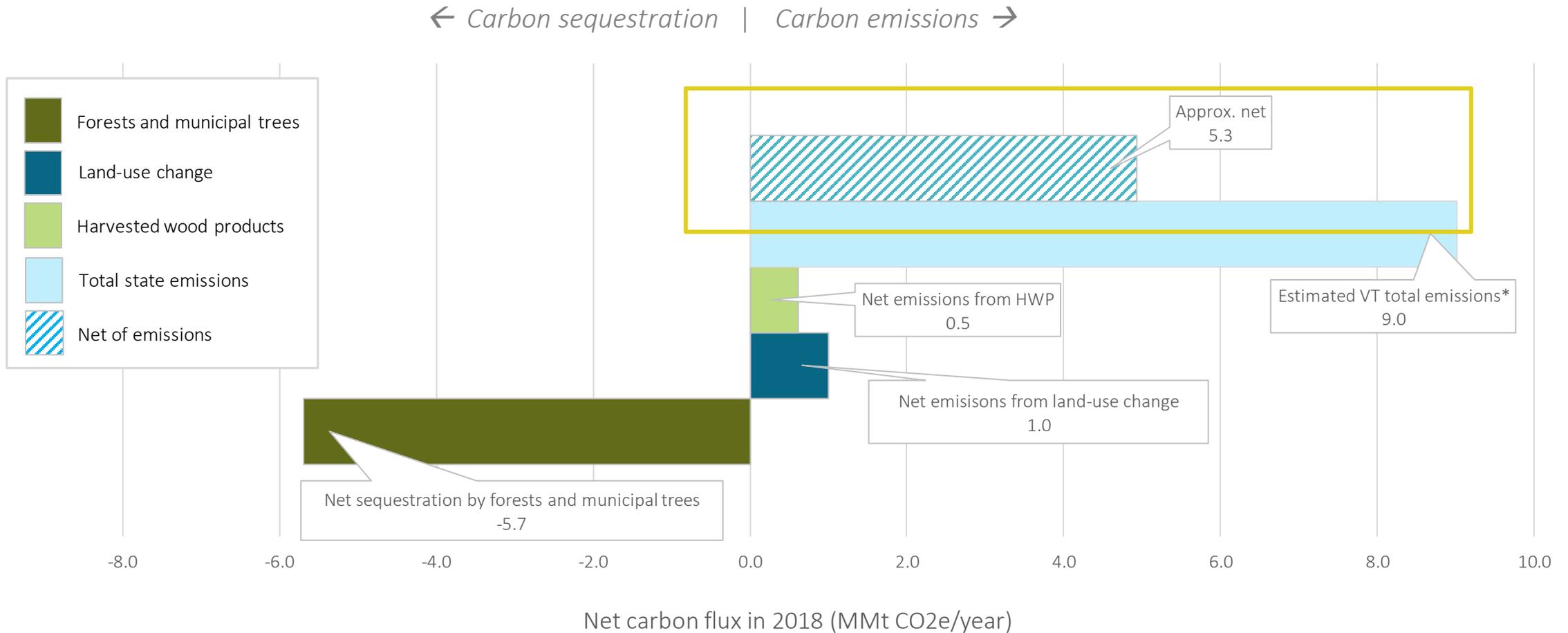
# Across the VT forest sector, there are carbon sinks and sources

Note: estimating carbon is difficult and these values are approximate



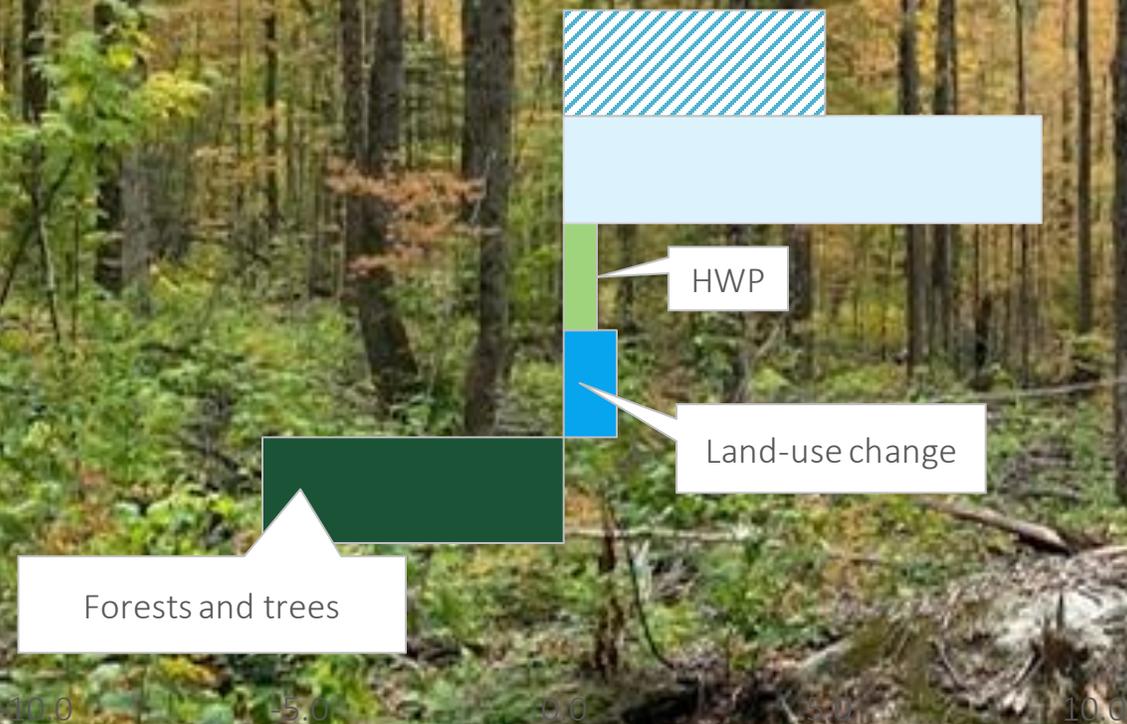
Kosiba AM. 2021. Vermont Forest Carbon Inventory. Data sources: Domke et al. (2020) forest and tree sequestration and land use change estimates; Dugan et al. (2020) HWP emissions and substitution estimates

When we combine the sinks and sources estimated for 2018, the forest sector took in ~42% of state annual emissions



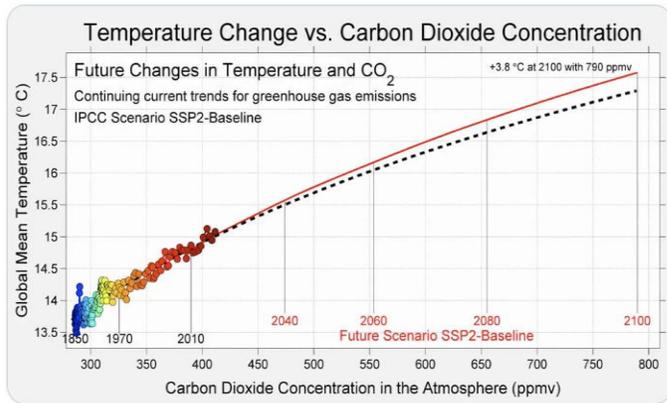
Kosiba AM. 2021. Vermont Forest Carbon Inventory. Note that these forest sector values are not included in the Vermont GHG Inventory. Data source for state emissions: VT ANR GHG Inventory (2020), estimate for 2018

# Opportunities to maintain and increase the mitigation potential of the forest sector



- Maintain or increase carbon sequestration of forests through good stewardship and ecological silviculture
- Maintain or increase carbon sequestration of municipal trees through good stewardship and additional tree planting
- Reduce carbon emissions from land-use conversion and maintain the forest carbon potential
- Decrease net HWP emissions by increasing use of wood as substitutes, durable wood products

Climate change itself poses a risk to the ability of forests to sequester and store carbon, and to keep it stored for long periods of time



Source: Berkeley Earth

- Increased mortality?
- Lower growth rates?
- More stressors?
- More disturbances?
- Faster decomposition rates?

**Climate-resilient forests are the best path to ensure a long-term climate mitigation effect**

“Resilience” means the capacity of forests to withstand and recover from climatic events, trends, and disruptions.

“Adaptation” means reducing the vulnerability and advancing resilience through enhancements to, or avoiding degradation of, forests.  
(from the VT Global Warming Solutions Act)

**Forest Insects and Climate Change**

Deepa S. Pureswaran, Alain Roques, Andrea Battisti  
[Current Forestry Reports](#) 4, 35–50 (2018) | [Cite this article](#)  
 14k Accesses | 83 Citations | 72 Altmetric | [Metrics](#)

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Science • 23 Jan 2009 • Vol 323, Issue 5913 • pp. 521–524 • DOI: 10.1126/science.1166755

**Tree mortality from drought, insects, and their interactions in a changing climate**

William R. L. Anderegg, Jeffrey A. Hicke, Rosie A. Fisher, Craig D. Allen, Juliann Aukema, Barbara Bentz, Sharon Hood, Jeremy W. Lichstein, Alison K. Macalady, Nate McDowell, Yude Pan ... See all authors

**Climate variability drives recent tree mortality in Europe**

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 First published: 17 April 2017 | <https://doi.org/10.1111/gcb.13724> | Citations: 99

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 First published: 22 July 2013 | <https://doi.org/10.1111/ele.12151> | Citations: 129

**Hemlock Declines Rapidly with Hemlock Woolly Adelgid Infestation: Impacts on the Carbon Cycle of Southern Appalachian Forests**

Arci E. Buckles, Nina Wurzbarger, Chelso R. Ford, Ronald L. Hendrick, James M. Vose, Brian D. Kloeppel



A photograph of a misty forest. The scene is dominated by tall, slender evergreen trees. In the foreground, several large tree trunks are covered in thick, vibrant green moss. The ground is also covered in moss and fallen branches. The background is shrouded in a soft, white mist, creating a sense of depth and atmosphere. The overall color palette is muted greens, browns, and greys, with the white mist providing a stark contrast.

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