# Wild Carbon

## The Science behind Carbon and Conservation

Mark Anderson PhD.
Director of Conservation Science
The Nature Conservancy,
Center for Resilient Conservation

# Old Forests

**Resilience**

**Diversity**

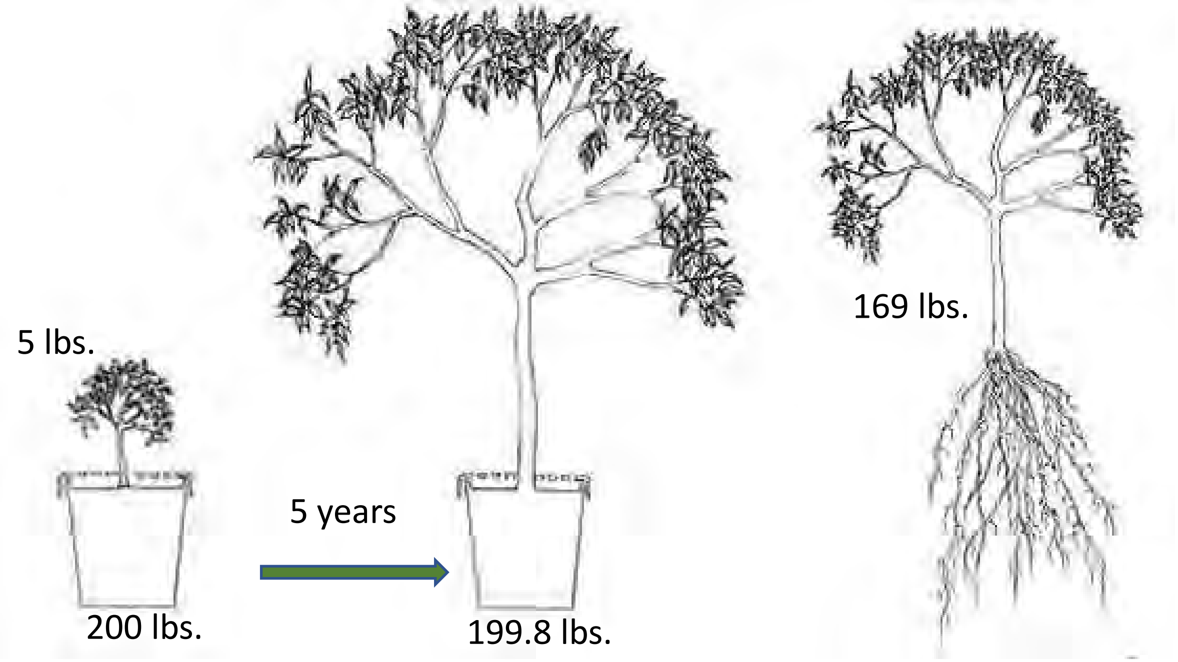
**Ethics**

**Carbon**

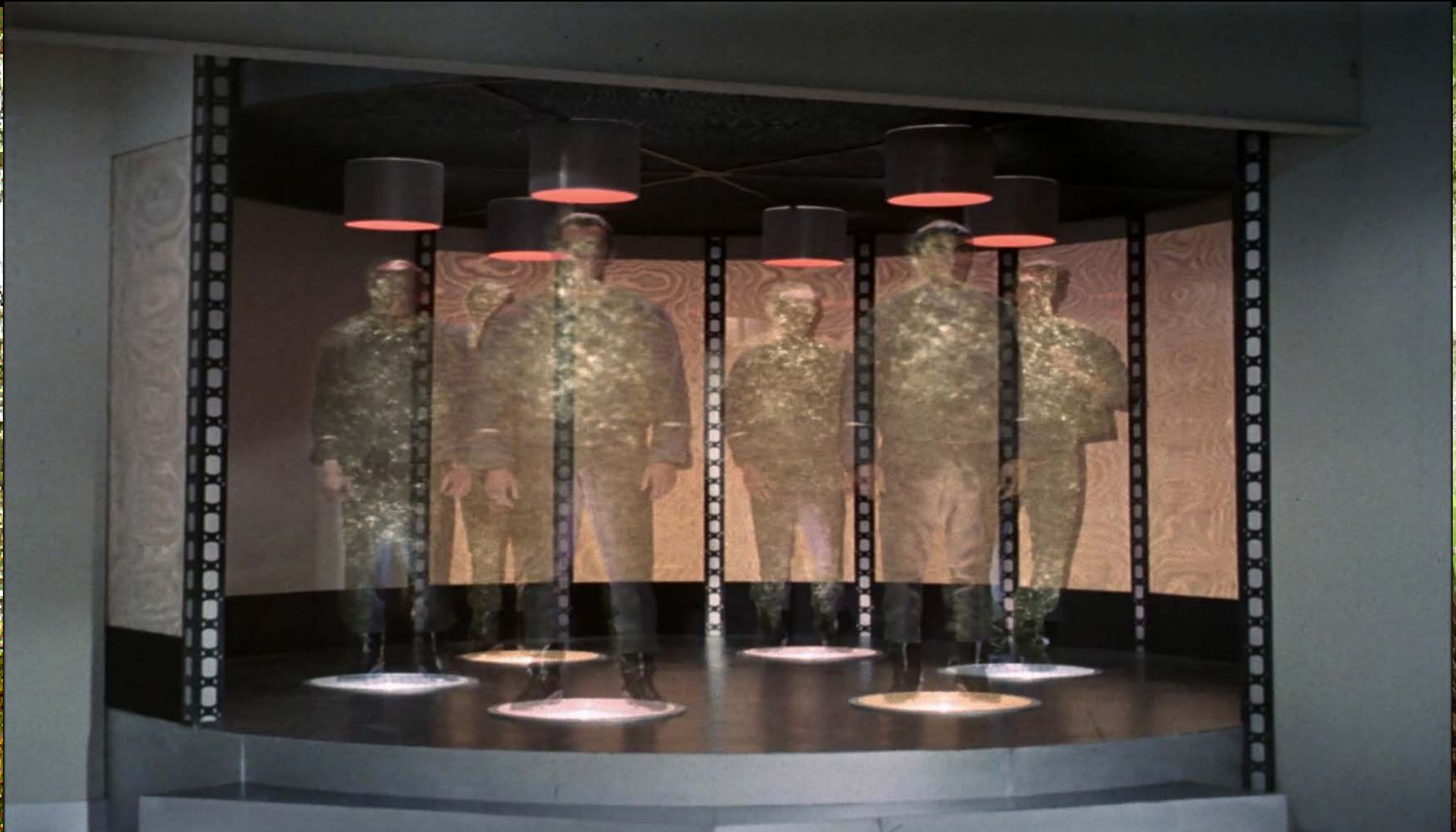
# Where does Plant Matter Come From?

Jan Baptist Van Helmont
1649

Joseph Priestly
1772

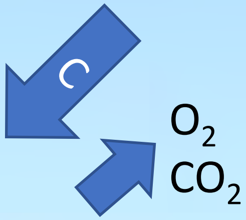



# Where does Plant Matter Come From?



# Living Solar Collectors

## Leaf Area Index

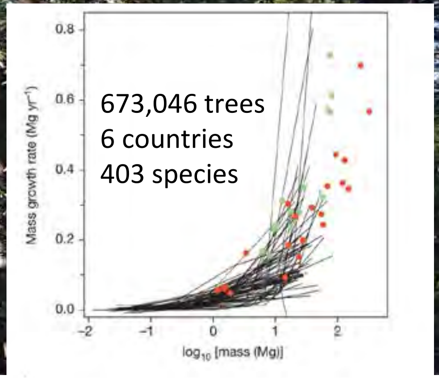



# Living Solar Collectors

## Leaf Area Index

" A single big tree can add the same amount of carbon to the forest within a year as is contained in an entire mid-sized tree."


$O_2$
$CO_2$

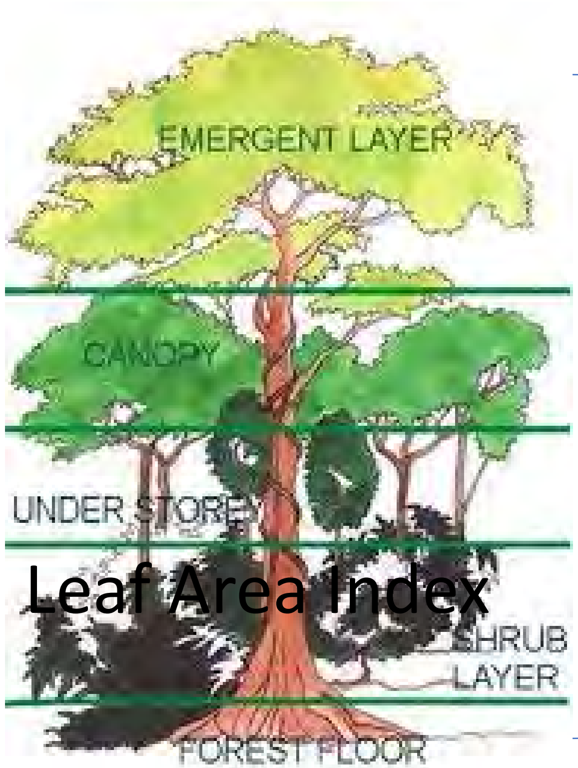



***Stephenson et al. 2014****. Rate of tree carbon accumulation increases continuously with tree size Nature 507*

# Carbon in Forest Stands

## Sequestration

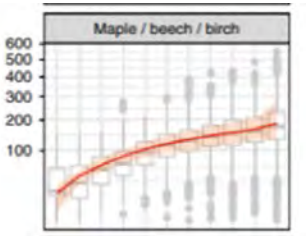
Annual Uptake of Carbon




Leaf Area Index

Maximize the LAI

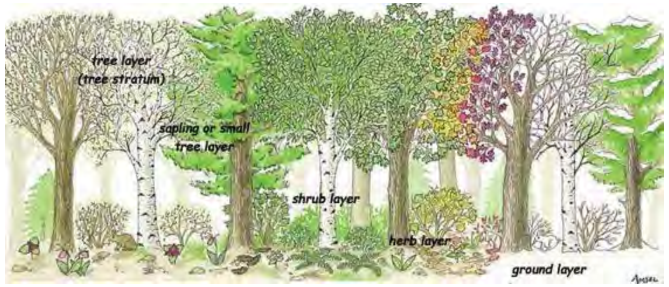

Structurally complex forests have higher vegetation area indices, absorb more light and used light more efficiently to power biomass production.
Gough et al 2019




Where does the extra carbon go?

## Storage

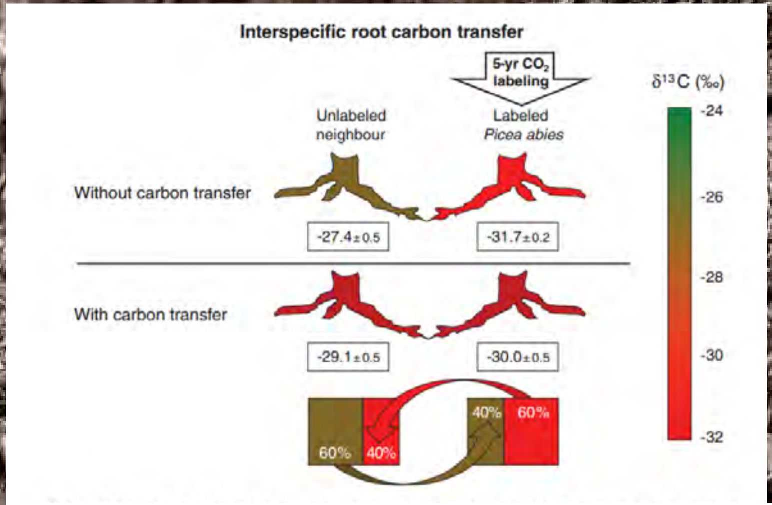
Accumulation of Carbon over time = Carbon Pools





Awesome Leaf Area Index!

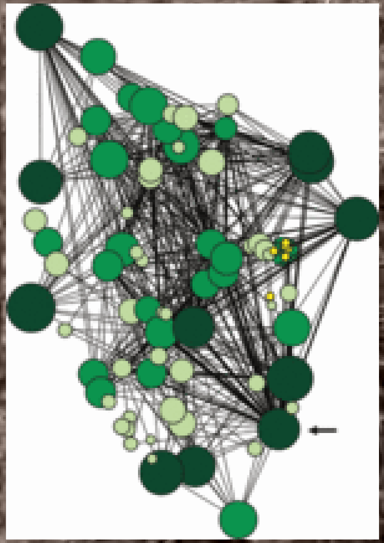
# Carbon Sharing

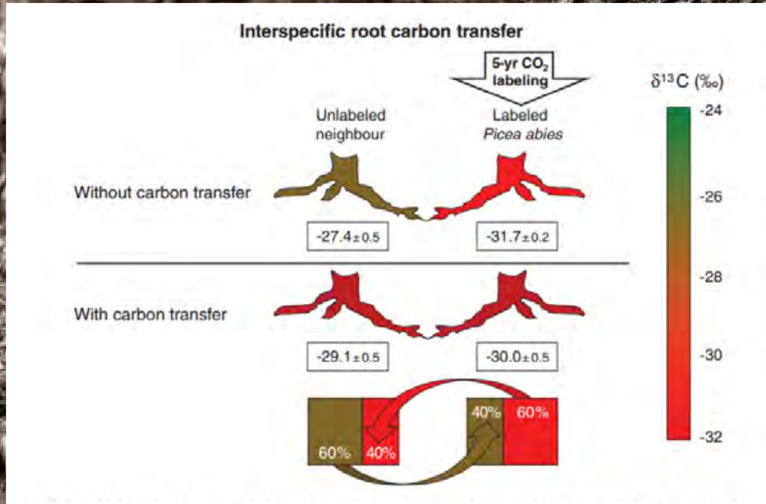



Up to 40% of the carbon in the fine roots are shared.
Old trees are central, favor offspring

***Klein et al. 2016.*** *Belowground carbon trade among tall trees in a temperate forest*
***Simard et al. 2015****. Resources transfer between plants via ECM networks*

# Carbon Sharing



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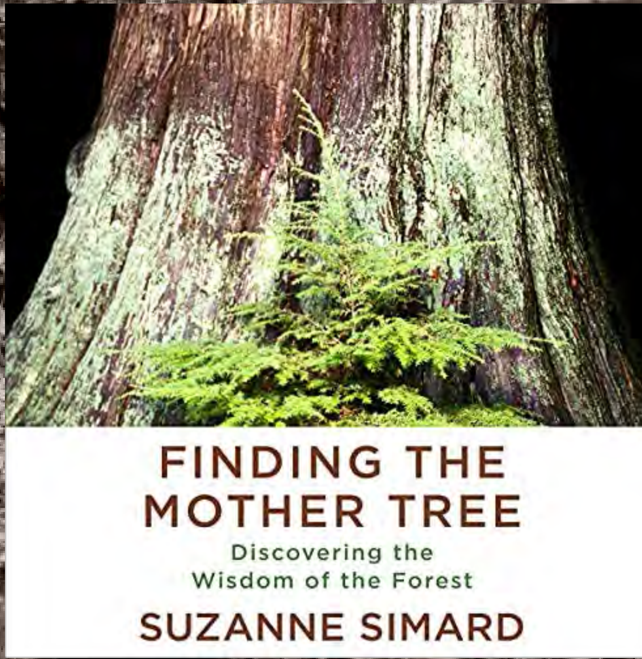
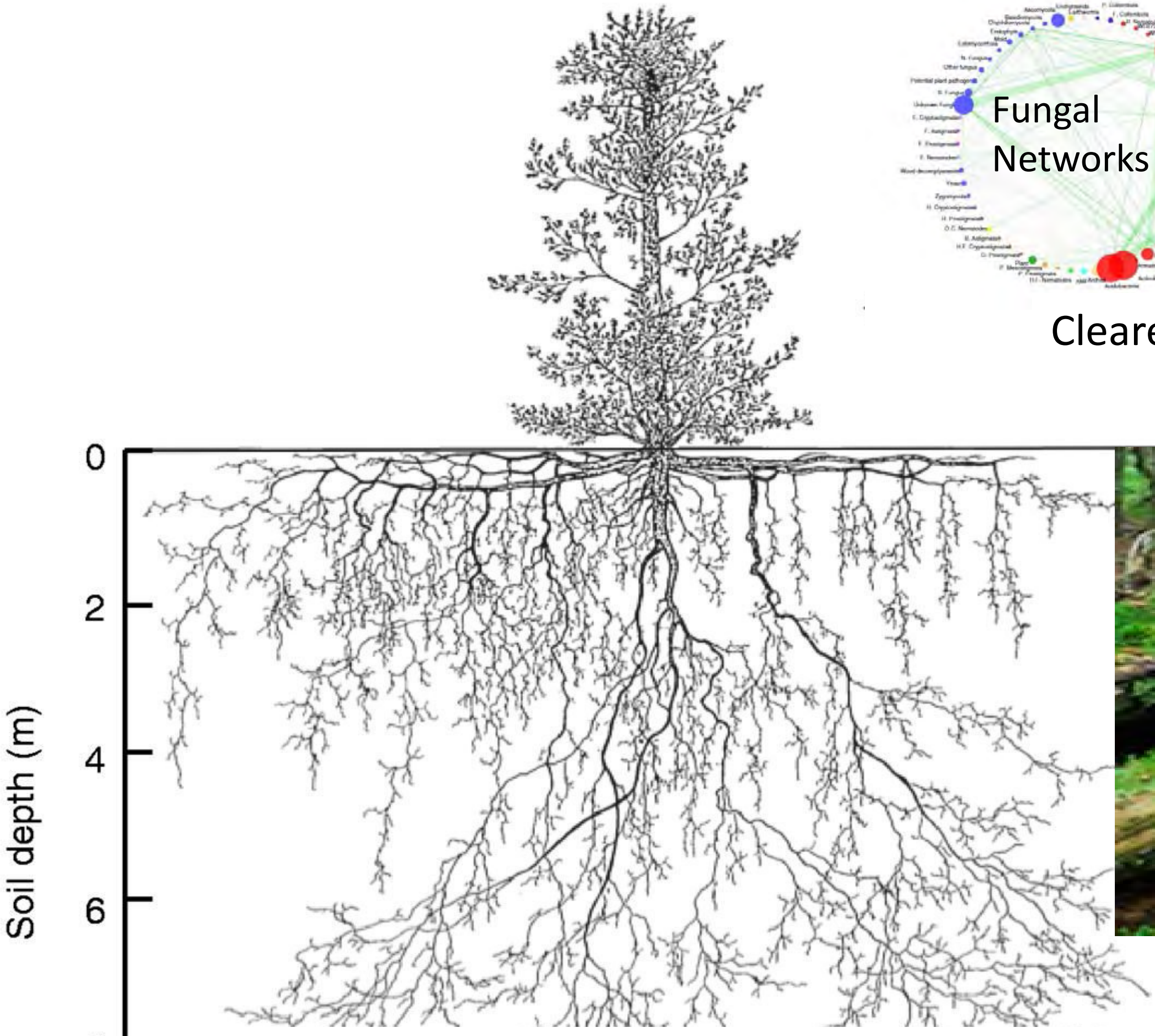
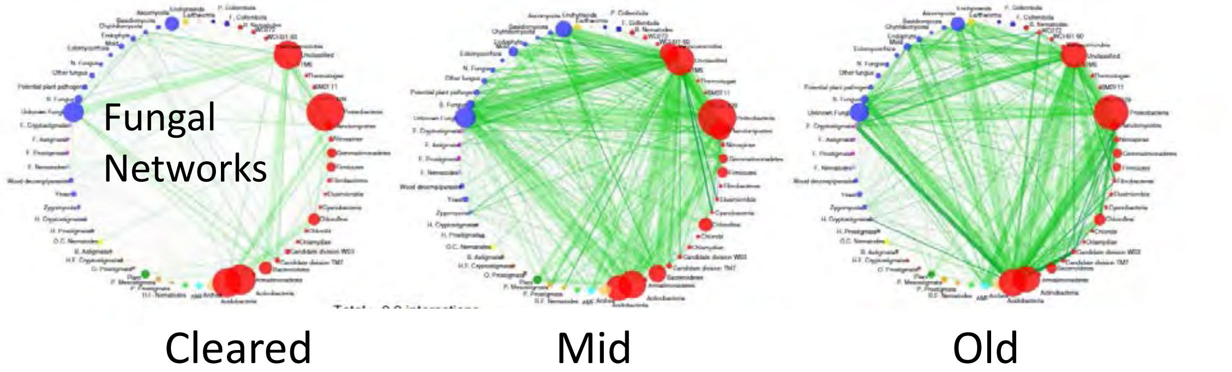
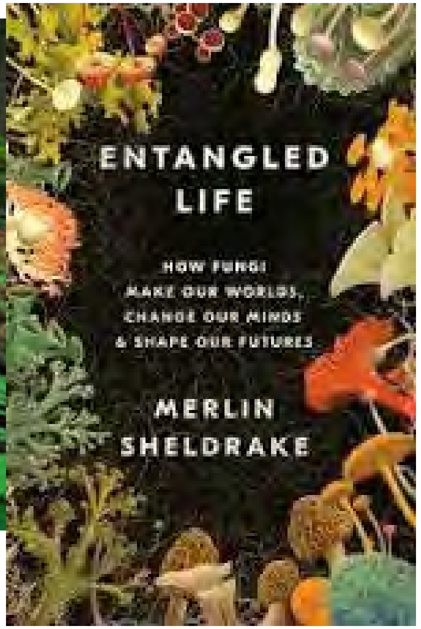


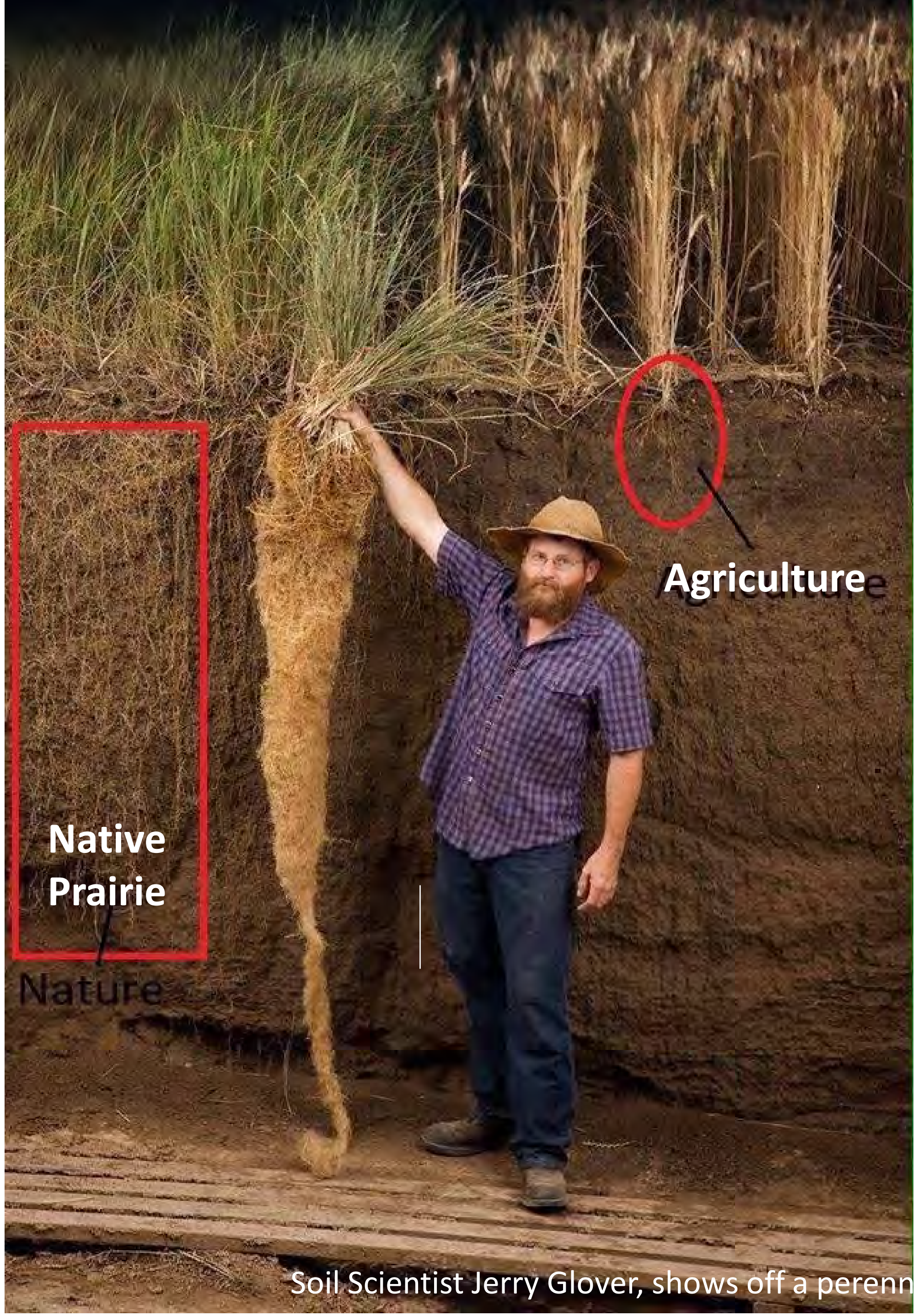
# Below-Ground Legacies



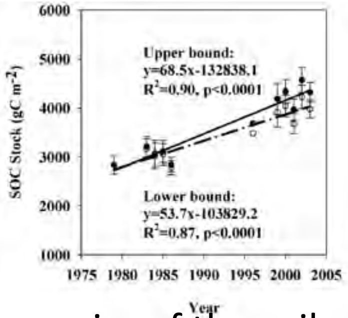




Over time the connectance of species in the soil community increases, carbon and nutrient uptake becomes more efficient. ***Morrie et al. 2017*** *Source: Soil networks become more connected and take up more carbon as nature restoration progresses*




# Soil Carbon

Soil
Organic
Carbon




**Steady State?** Zhou et al 2017 24-year dynamics of the soil carbon in an old growth forest at China's Dinghushan Biosphere Reserve. They found that soils in the top 20-cm soil layer accumulated atmospheric carbon at an unexpectedly high rate: 0.61 Mg C ha year.

**Table 2.—Example reforestation table with regional estimates of timber volume and carbon stocks on forest land after clearcut harvest for maple-beech-birch stands in the Northeast**

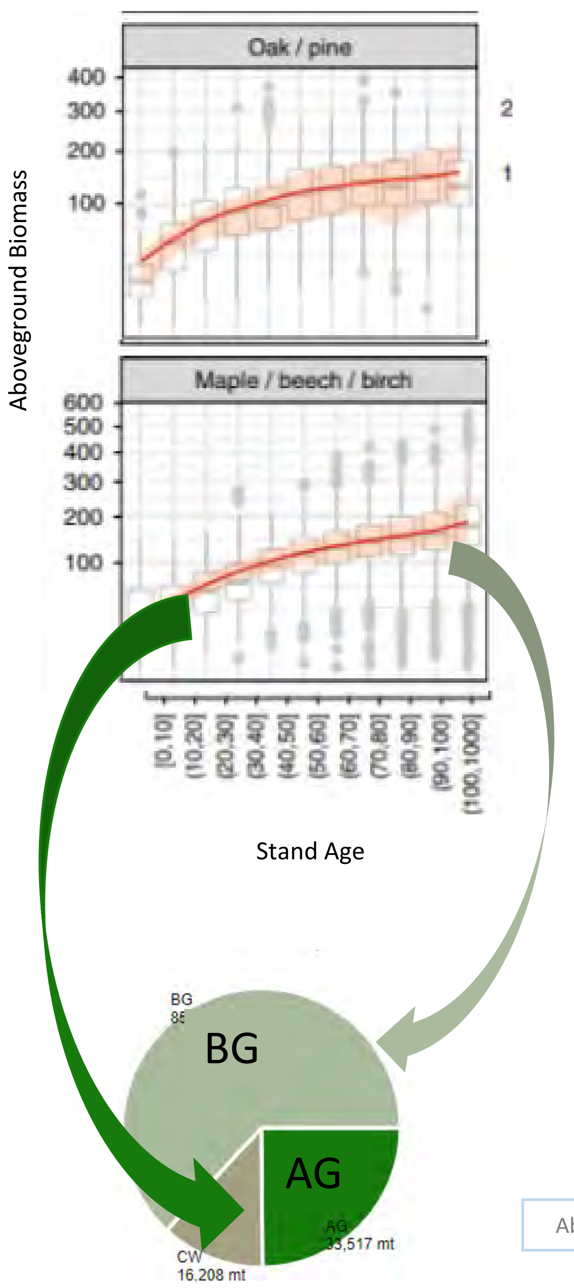
| Age | Mean volume | Mean carbon density | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Live tree | Standing dead tree | Under-story | Down dead wood | Forest floor | Soil organic | Total nonsoil |
| *years* | *m³/ha* | *tonnes carbon/hectare* | | | | | | |
| 0 | 0.0 | 0.0 | 0.0 | 2.1 | 32.0 | 27.7 | 69.6 | 61.8 |
| 5 | 0.0 | 7.4 | 0.7 | 2.1 | 21.7 | 20.3 | 69.6 | 52.2 |
| 15 | 28.0 | 31.8 | 3.2 | 1.9 | 11.5 | 16.3 | 69.6 | 64.7 |
| 25 | 58.1 | 53.2 | 5.3 | 1.8 | 7.8 | 17.6 | 69.6 | 85.7 |
| 35 | 89.6 | 72.8 | 6.0 | 1.7 | 6.9 | 20.3 | 69.6 | 107.8 |
| 45 | 119.1 | 87.8 | 6.6 | 1.7 | 7.0 | 23.0 | 69.6 | 126.0 |
| 55 | 146.6 | 101.1 | 7.0 | 1.7 | 7.5 | 25.3 | 69.6 | 142.7 |
| 65 | 172.1 | 113.1 | 7.4 | 1.7 | 8.2 | 27.4 | 69.6 | 157.7 |
| 75 | 195.6 | 123.8 | 7.7 | 1.7 | 8.8 | 29.2 | 69.6 | 171.2 |
| 85 | 217.1 | 133.5 | 7.9 | 1.7 | 9.5 | 30.7 | 69.6 | 183.2 |
| 95 | 236.6 | 142.1 | 8.1 | 1.7 | 10.1 | 32.0 | 69.6 | 193.9 |
| 105 | 254.1 | 149.7 | 8.3 | 1.6 | 10.6 | 33.1 | 69.6 | 203.4 |
| 115 | 269.7 | 156.3 | 8.5 | 1.6 | 11.1 | 34.2 | 69.6 | 211.7 |
| 125 | 283.2 | 162.1 | 8.6 | 1.6 | 11.5 | 35.1 | 69.6 | 218.8 |

Smith et al 2016. Calculating Forest Carbon in US

# Allocation

When the stand is young most of the carbon is allocated to aboveground growth, after 80-90 years, more of the  carbon is allocated to other pools

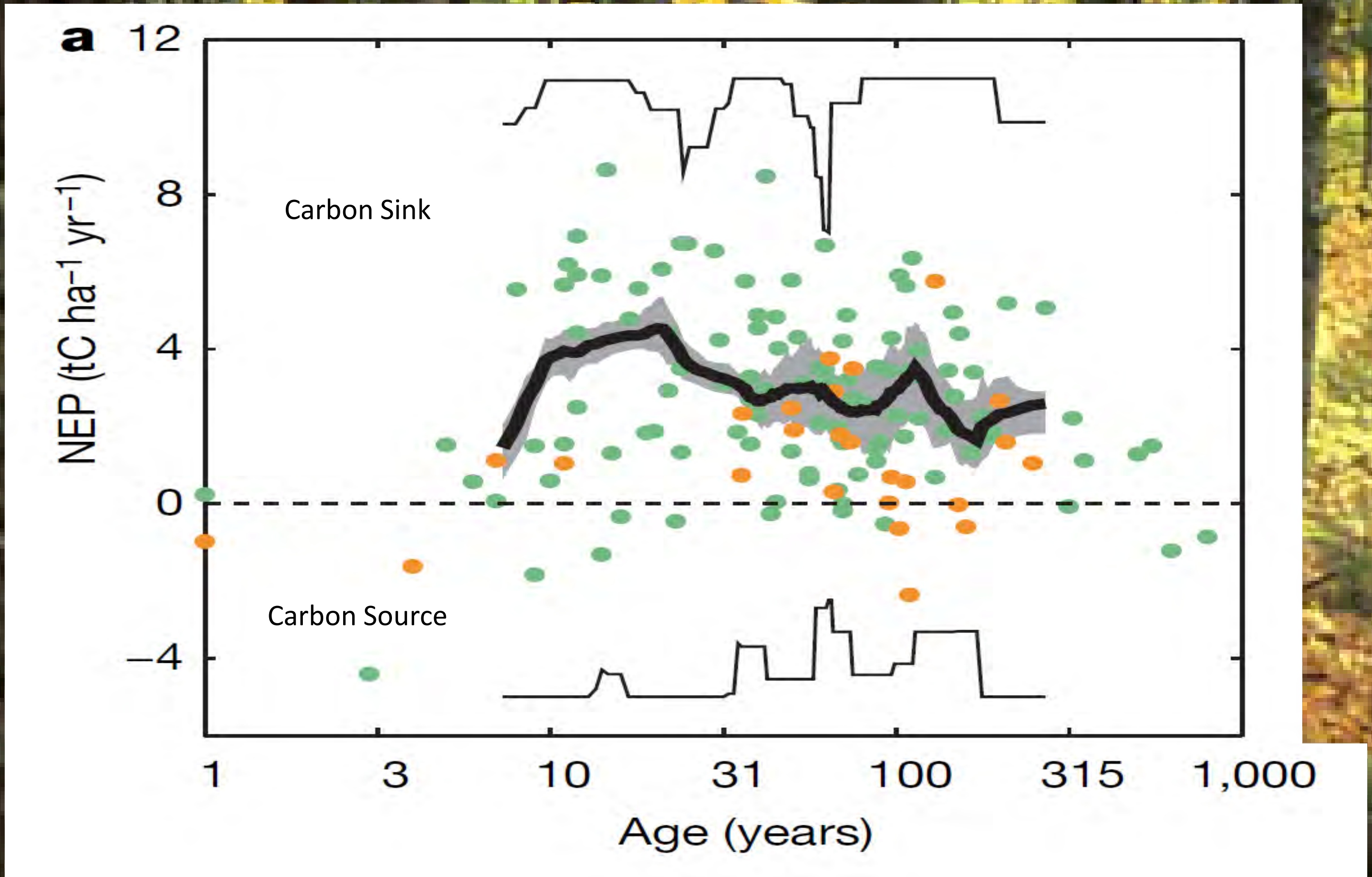
Zhu et al 2018



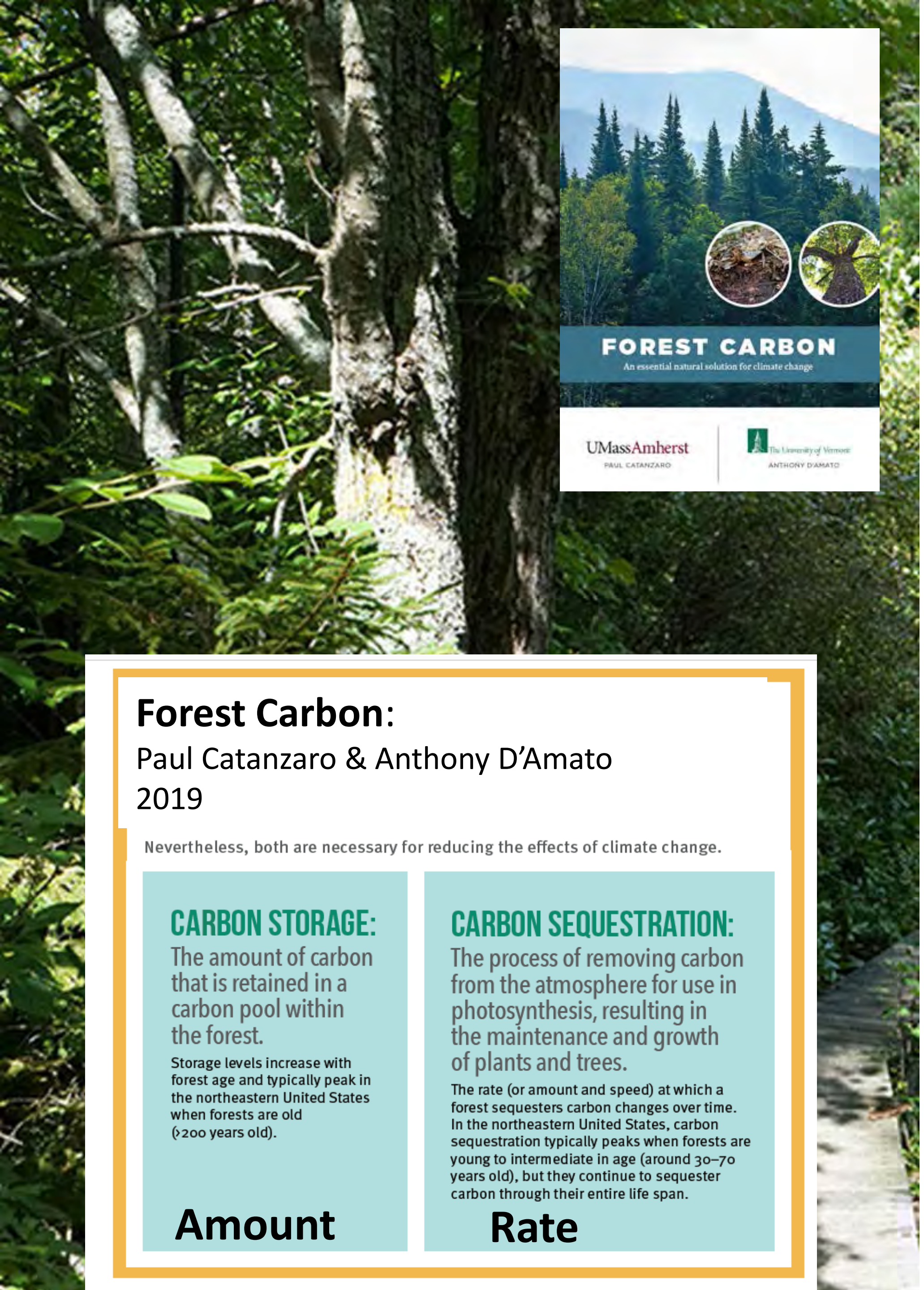

Above ground

# Carbon Storage

"Old-growth forests accumulate carbon for centuries and contain large quantities of it."




***Luyssaert et al. 2008***. *Old-growth forests as global carbon sinks. Nature 455. Sept 11 (519 published carbon flux estimates 15-800 yr stands)*




**Forest Carbon**:
Paul Catanzaro & Anthony D'Amato
2019

Nevertheless, both are necessary for reducing the effects of climate change.

**CARBON STORAGE:**
The amount of carbon that is retained in a carbon pool within the forest.

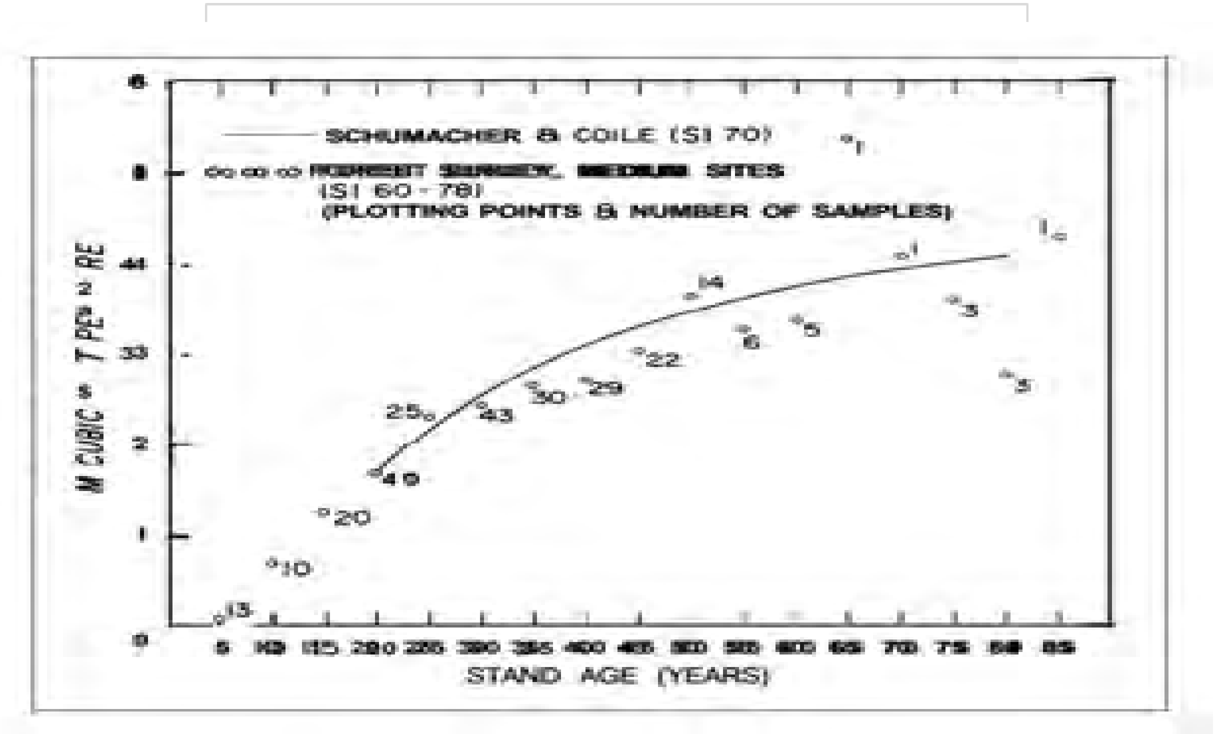
Storage levels increase with forest age and typically peak in the northeastern United States when forests are old (>200 years old).

**Amount**

**CARBON SEQUESTRATION:**
The process of removing carbon from the atmosphere for use in photosynthesis, resulting in the maintenance and growth of plants and trees.

The rate (or amount and speed) at which a forest sequesters carbon changes over time. In the northeastern United States, carbon sequestration typically peaks when forests are young to intermediate in age (around 30–70 years old), but they continue to sequester carbon through their entire life span.

**Rate**

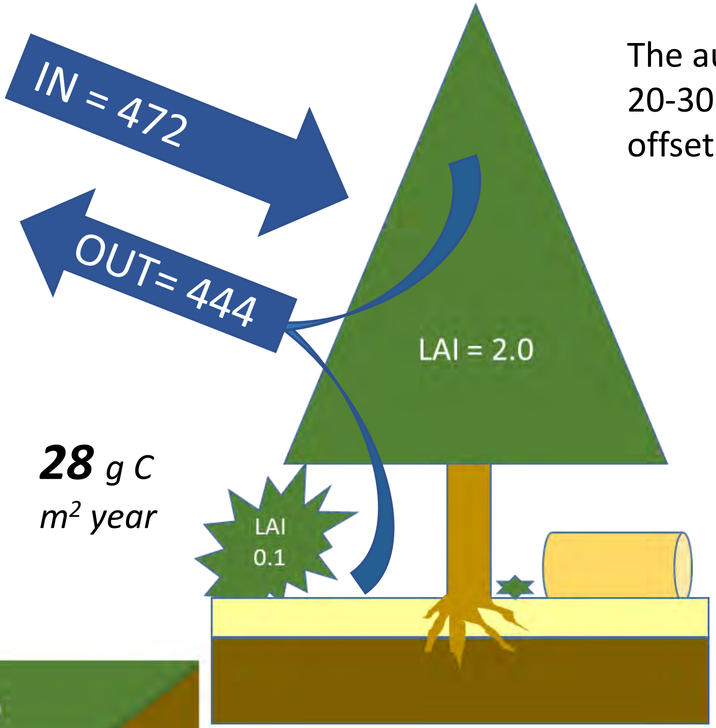



The **rate** at which a forest sequesters carbon typically peaks when forests are young to intermediate age (30-70 years old)

Do young fast- growing forests sequester more carbon?

# Old vs Young Forest

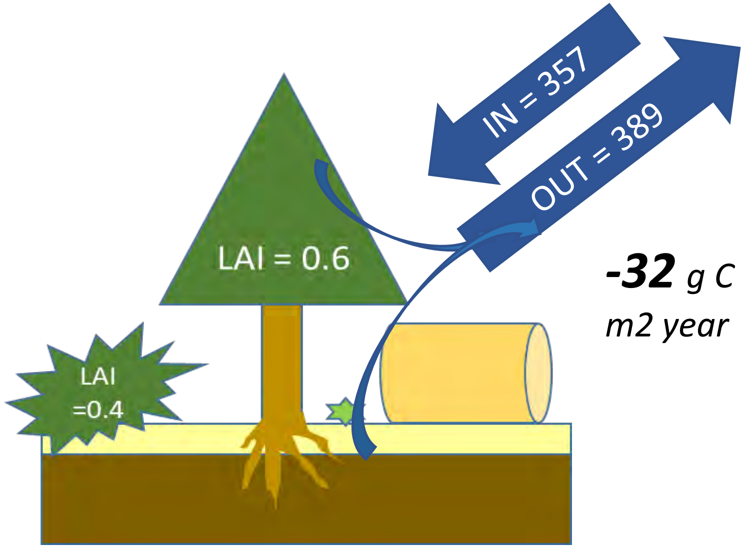
The authors conclude:
20-30 years before LAI can offset respiration





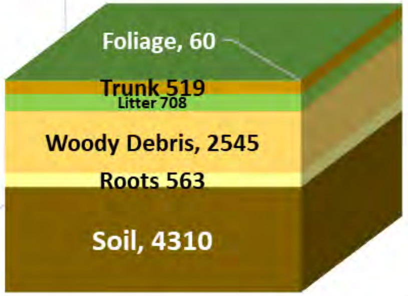
**Old Forest**
50 & 250 yrs.

Carbon Stock
= ***20,901*** *g C m²*



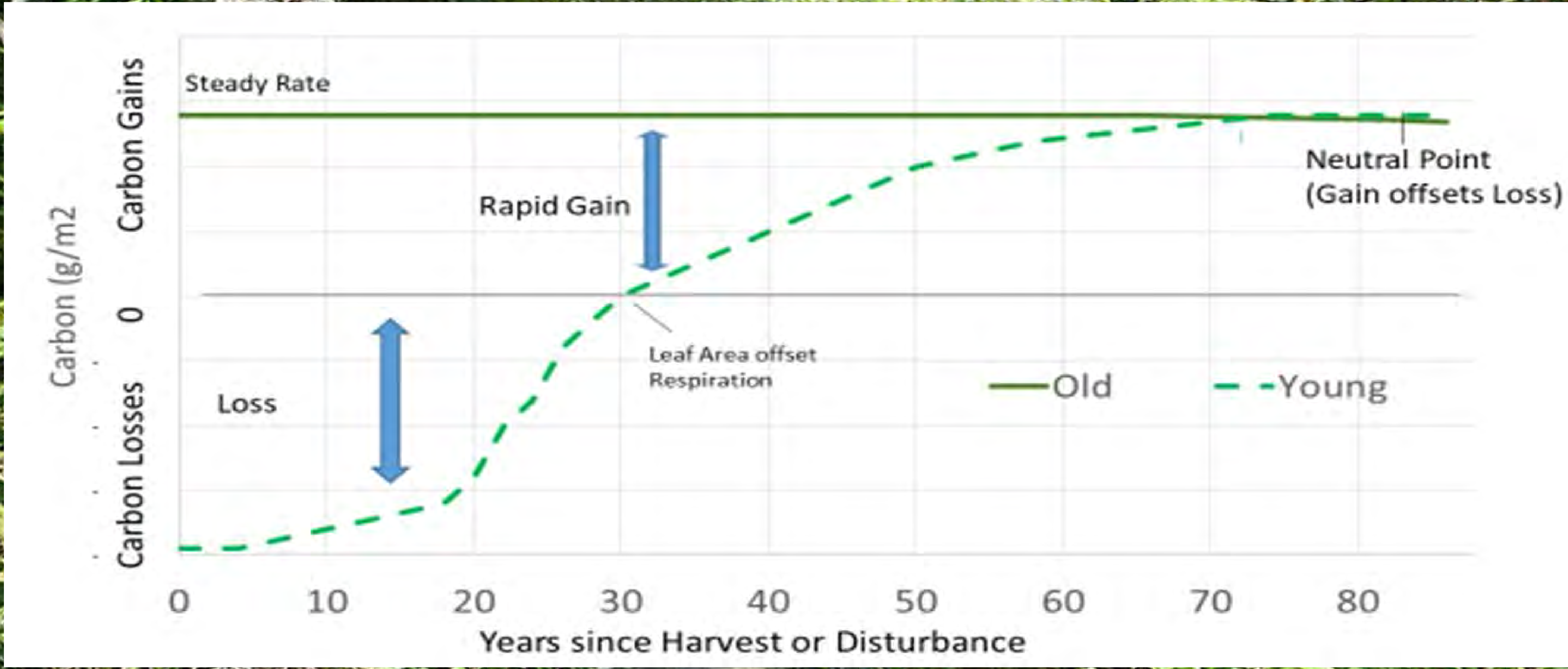

**Young Forest**
20 yrs. Clearcut

Carbon Stock
= ***9,939*** *g C m²*




**Beverly Law**, Oregon State
Carbon storage and fluxes in ponderosa pine forests at different developmental stages

# General Model




Original Wood (20%)

Soil Carbon (48%)

New C Wood (80yrs)

New C Soil

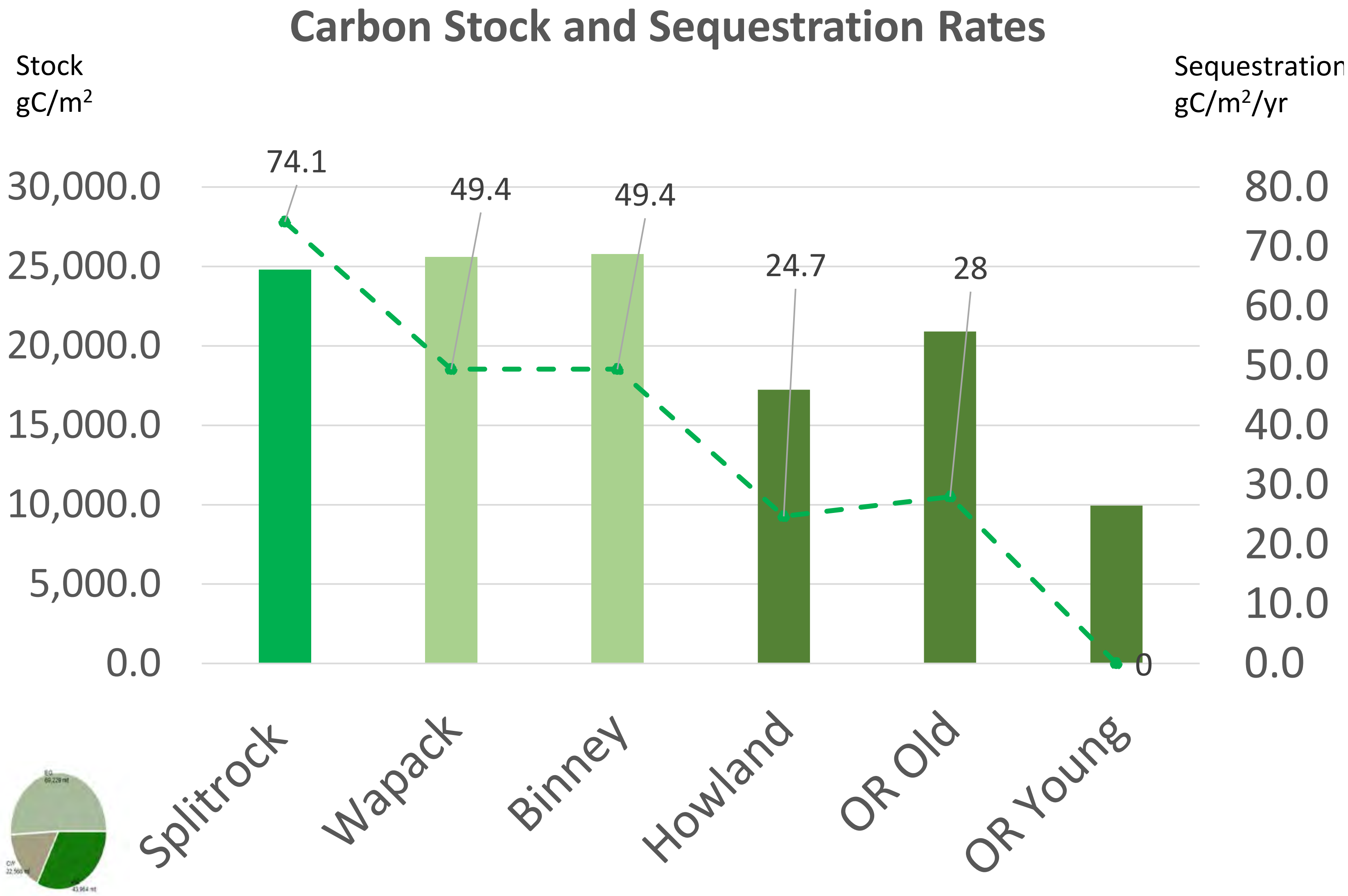
Ingerson, Ann. 2011. Carbon Storage Potential of Harvested Wood.


Splitrock (NH)

Wapack (Mixed)

Binney (Mixed)

Howland (S-F)

OR (Pine)

Carbon Stock and Sequestration Rates
Stock
gC/m2
Sequestration
gC/m2/yr
30,000.0
25,000.0
20,000.0
15,000.0
10,000.0
5,000.0
0.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
74.1
49.4
49.4
24.7
28
0
Splitrock
Wapack
Binney
Howland
OR Old
OR Young

# Summary so Far

- Trees extract carbon in proportion to their leaf area
- Complex old forest stands maximize annual uptake
- Forest stands sequester and store carbon every year
- Young stands allocate more carbon to wood production, Old stands allocate more carbon to roots, neighbors and the mycorrhizal network.
- Old forests store A LOT of carbon, but there are ways to grow and harvest trees that minimize sequestration losses and provide wood products. It takes time

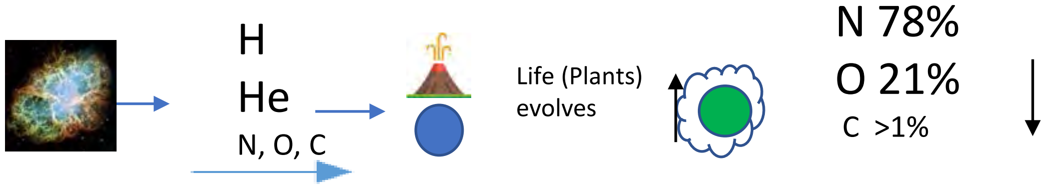
# Back to the Garden

Joseph Priestly
1772

Joni Mitchell
1969

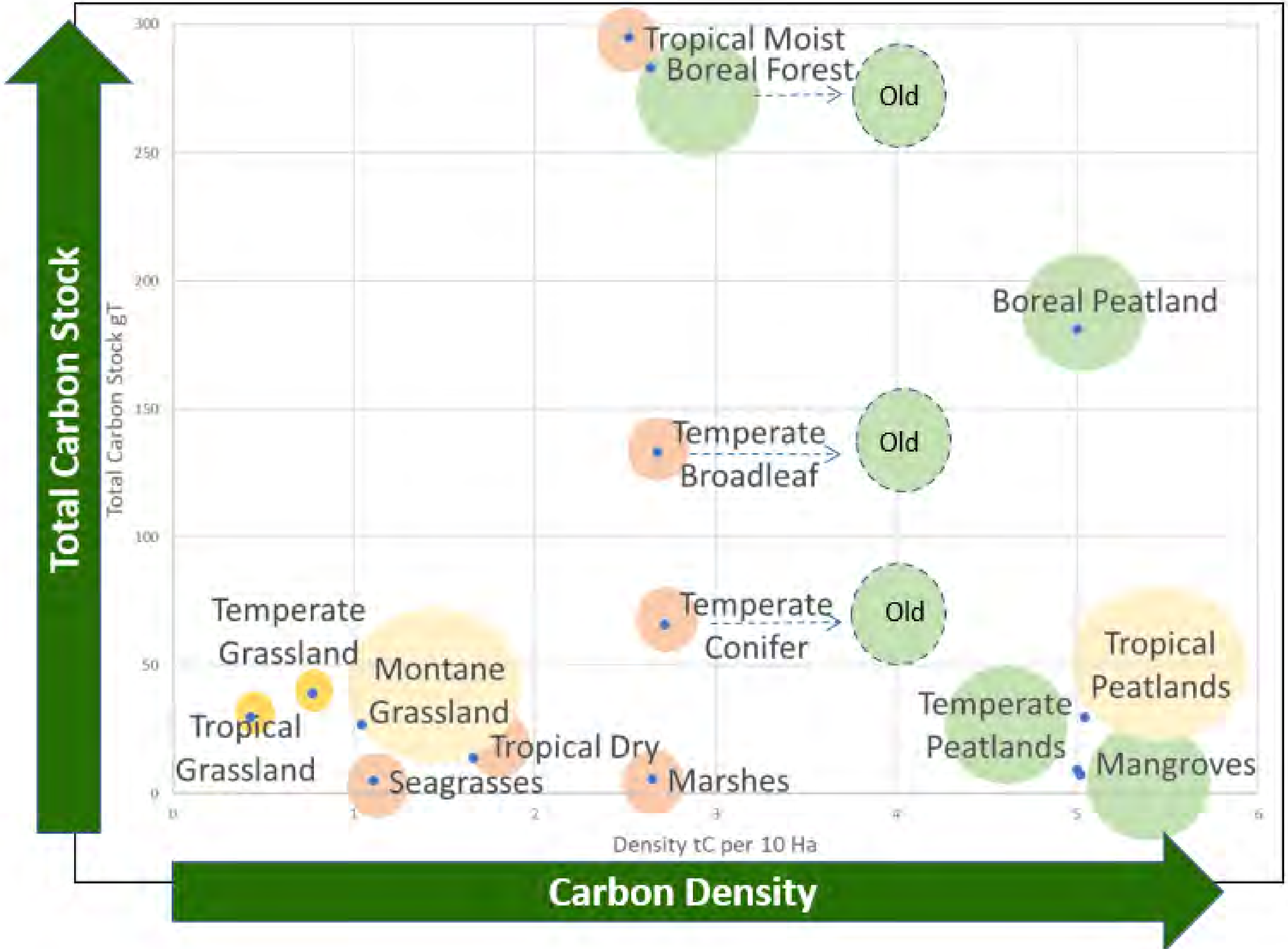

"We are stardust, Billion-year-old carbon*
We are golden, Caught in the devil's bargain
And we've got to get ourselves
Back to the garden"

**quoting Carl Sagan*



# Irrecoverable Carbon

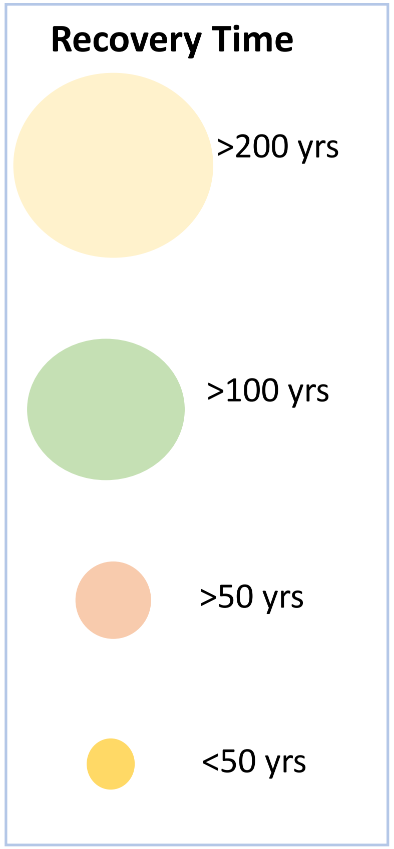
## Conserve Wild Carbon and Grow More





nature climate change
PERSPECTIVE


Protecting irrecoverable carbon in Earth's ecosystems




Data from Goldstein et al. 2020

# Natural Climate Solutions

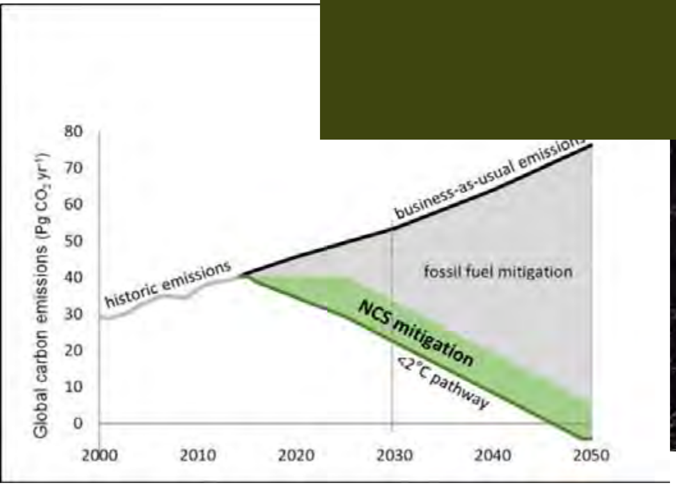
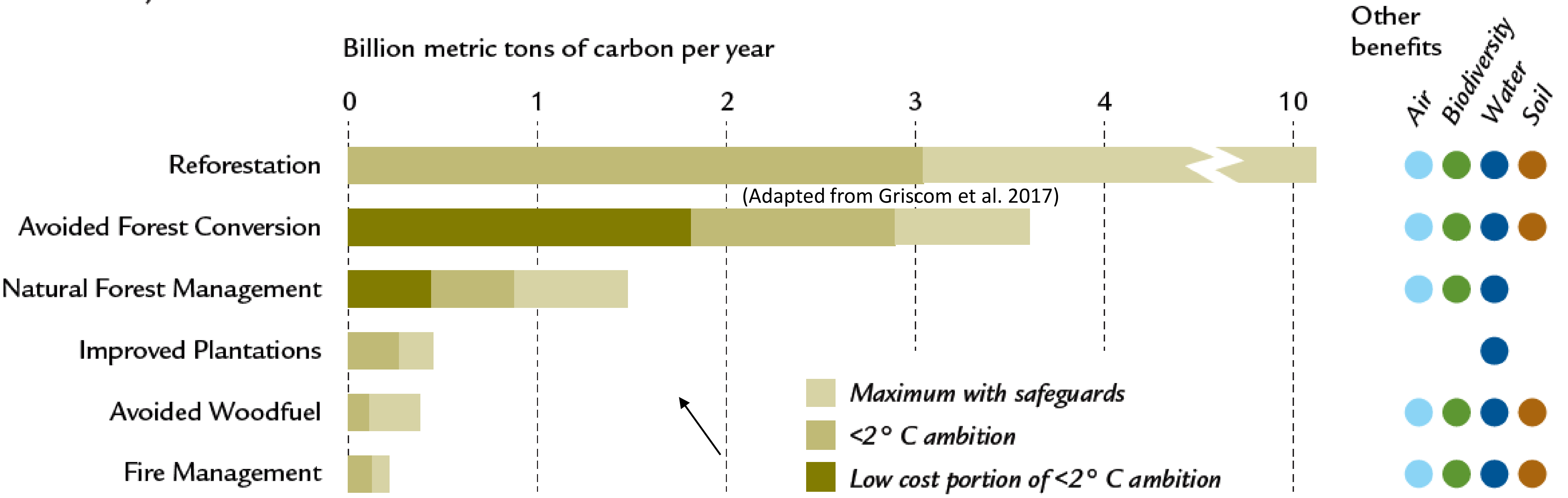
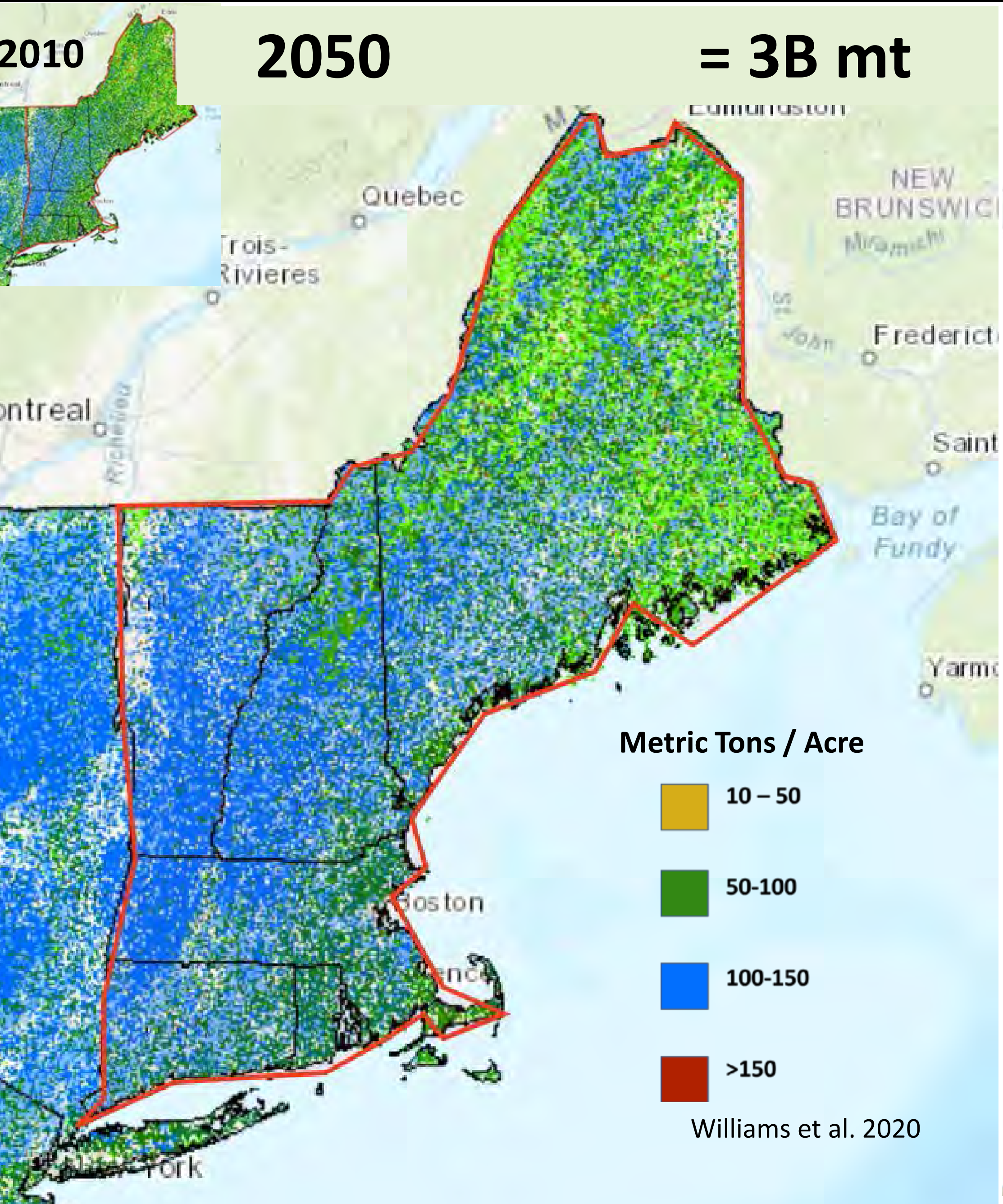



FIGURE 2) CLIMATE MITIGATION POTENTIAL




Climate mitigation potential of six forest pathways estimated global ambition to hold warming to <2° C. Darkest portions

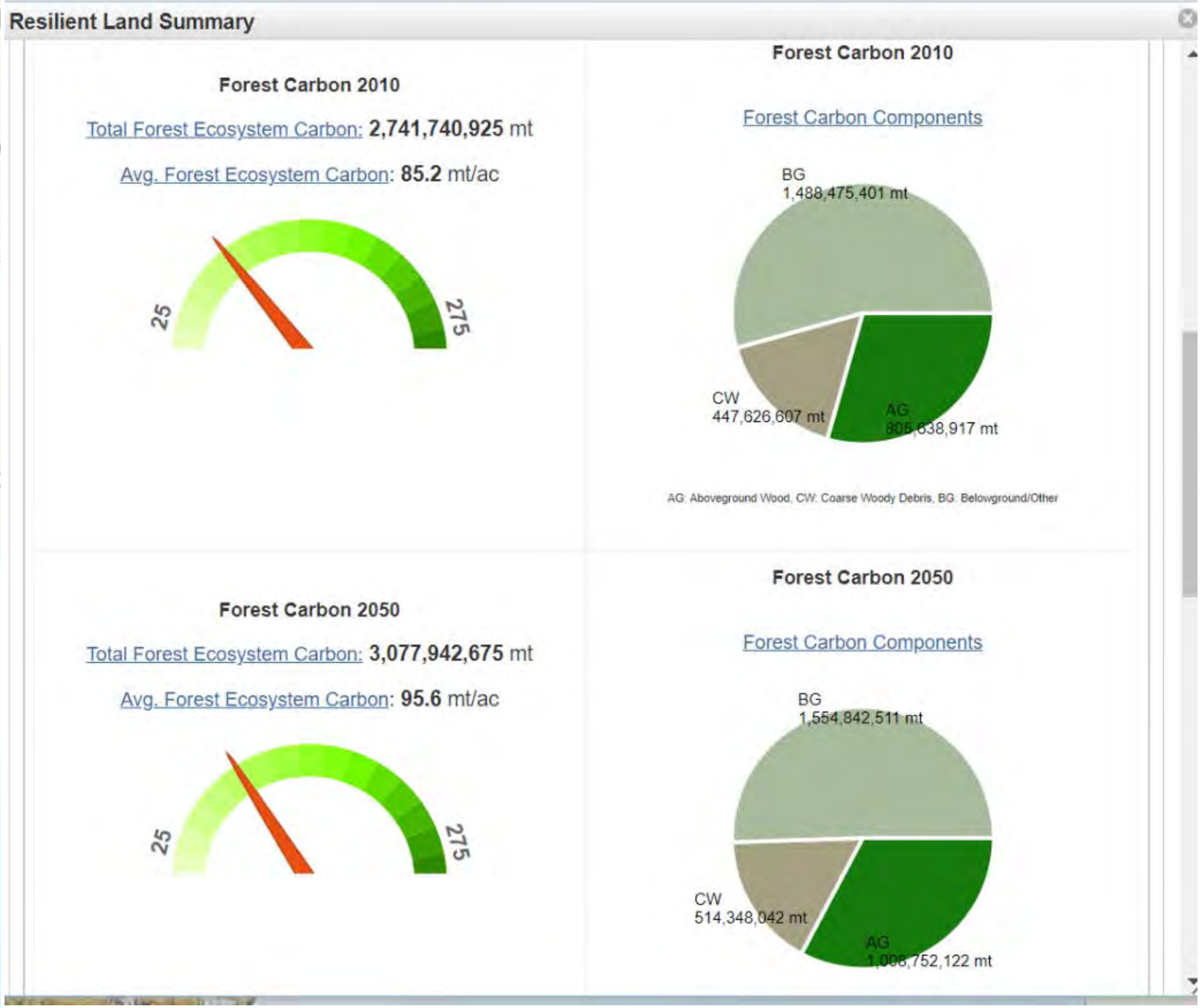
# Forest Carbon Stocks



Williams et al. 2020

**Sequesters 8.4 M metric tons per year**

Biden spending $1.2 B remove 2 M per year

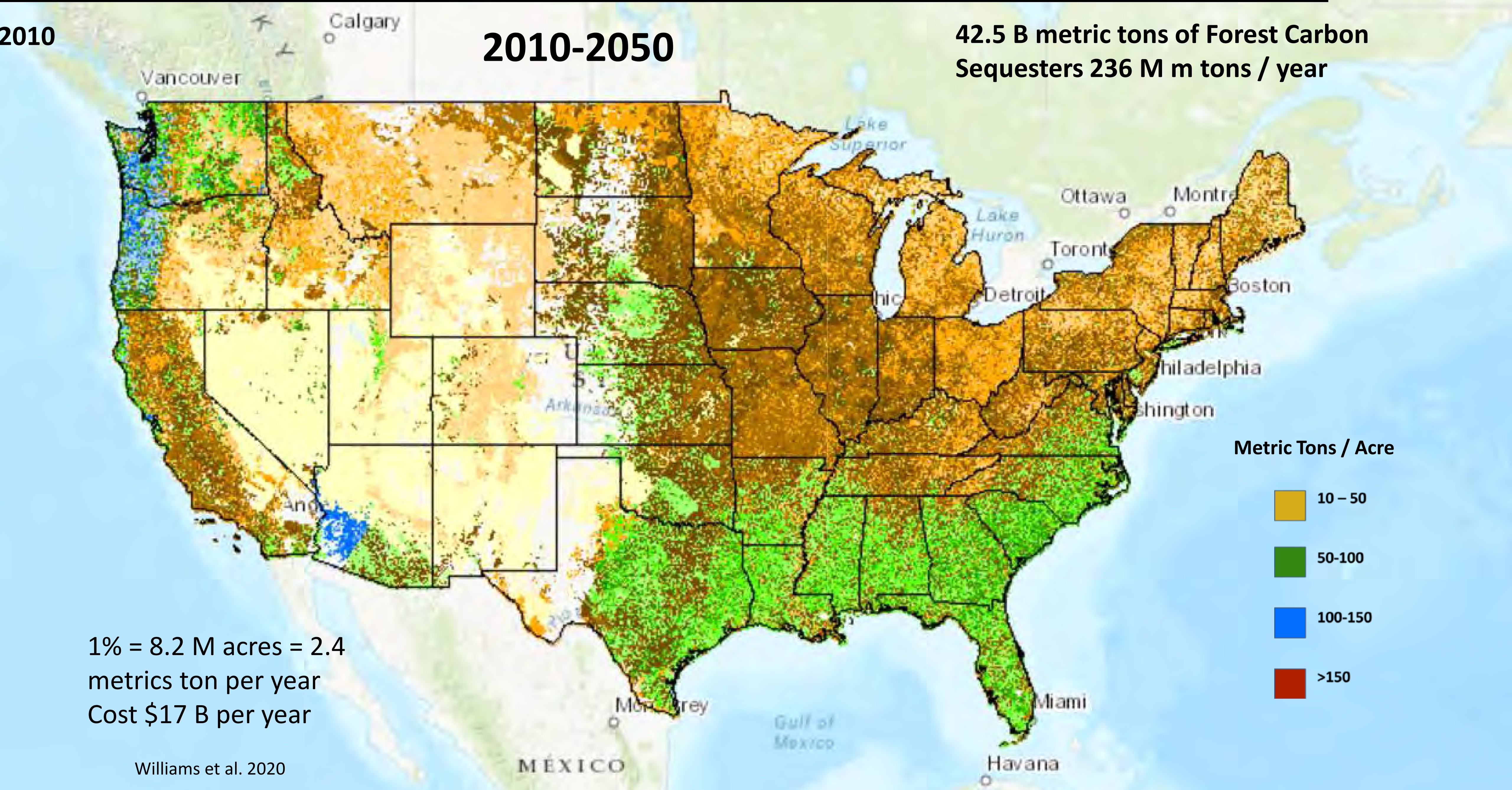


# Forest Carbon Stocks

2010

## 2010-2050

**42.5 B metric tons of Forest Carbon**
**Sequesters 236 M m tons / year**

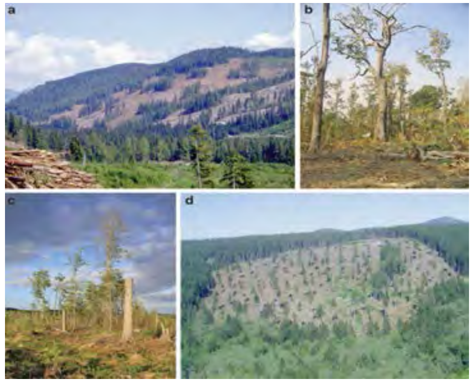



1% = 8.2 M acres = 2.4 metrics ton per year
Cost $17 B per year

Williams et al. 2020

# Carbon Friendly Forestry

## Soils, Retention Forestry, Whole Cycle Management



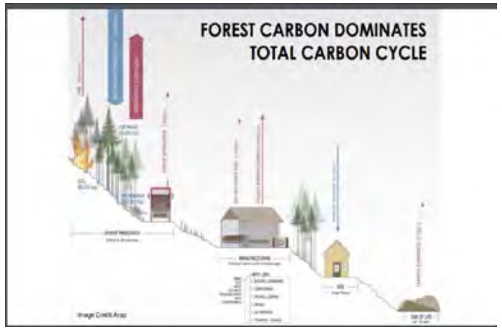
**Longer Rotations:** Let trees grow older and remain rooted and connected longer

**Retention Forestry**: A scientifically validated management approach that is modeled on natural processes. A portion of the original stand is left unlogged to maintain the continuity of structural and compositional diversity.  Leave old trees, leaf area. Manage for structural complexity.

*Gustafsson et al. 2012, Retention Forestry to Maintain Multifunctional Forests: A World Perspective*
*Ford,S.E., and Keeton,W.S. 2017 Enhanced carbon storage through management for old-growth characteristics in northern hardwood-conifer forests*

**Manage for Soils:** Intensive harvest depletes soil organic carbon far more then traditional whole stem harvest.  Increase research on maintaining soil carbon. Leave a mess

*Achat et al. 2015. Forest soil carbon is threatened by intensive biomass harvesting. Nature*




**Whole Cycle Management**: Reduce losses at all stages of the wood product carbon life cycle: processing, transportation, manufacturing, use

# All Types of Conservation

## Forests: a Natural Solution to Climate Change

Forests filter our drinking water, provide homes for wildlife and improve our health. Forests also fight climate change in many ways.

### Wildlands

Forest reserves, managed by nature and without harvesting, remove large amounts of carbon pollution from the air and store it in tree trunks, leaves, roots and soils. Protecting forests and allowing them to grow for centuries means they can store more carbon each year.

### Woodlands

With careful planning and management, most forests can produce wood products while also increasing the carbon stored in the forest over time. Locally harvested wood can replace building materials that have a larger carbon footprint, like steel and concrete, reducing carbon emissions.

Sometimes, forests have been so damaged by poor forest management, invasive species, or disease that they aren't storing as much carbon as they could. Restarting these forests by harvesting damaged and diseased trees may store more carbon over the long term.

Carbon exists in several places and forms:

**In the air:** At high concentrations in the air, carbon dioxide is a pollutant and a green-house gas that warms the planet.

**In plants:** Plants turn carbon dioxide into sugar (glucose). In this form, carbon is food for plants and other organisms in the forest.

**In wood:** Trees and shrubs turn carbon into cellulose. In this form, carbon can be stored long-term in tree trunks or in lumber.


### Trees in Cities

Trees planted in cities store carbon as they grow and reduce energy use from buildings shaded and sheltered by the trees. Just as importantly, trees also reduce asthma rates, heart disease and stress.

To tackle the climate challenge, we need to grow and protect forests, but that alone is not enough. We must also reduce fossil fuel use and adapt to the changes we're already seeing. **Learn more at: nature.org/climate**

The Nature Conservancy

**Permanent Protected Lands (Public and Private - Forever Wild)**

Gap 1: 2% Biodiversity w natural process

GAP 2: 3% Biodiversity w management

**Well Managed Multiple Use Lands (Public and Private)**

GAP 3: 11% Secured for Multiple Uses.

Well managed public lands and easements

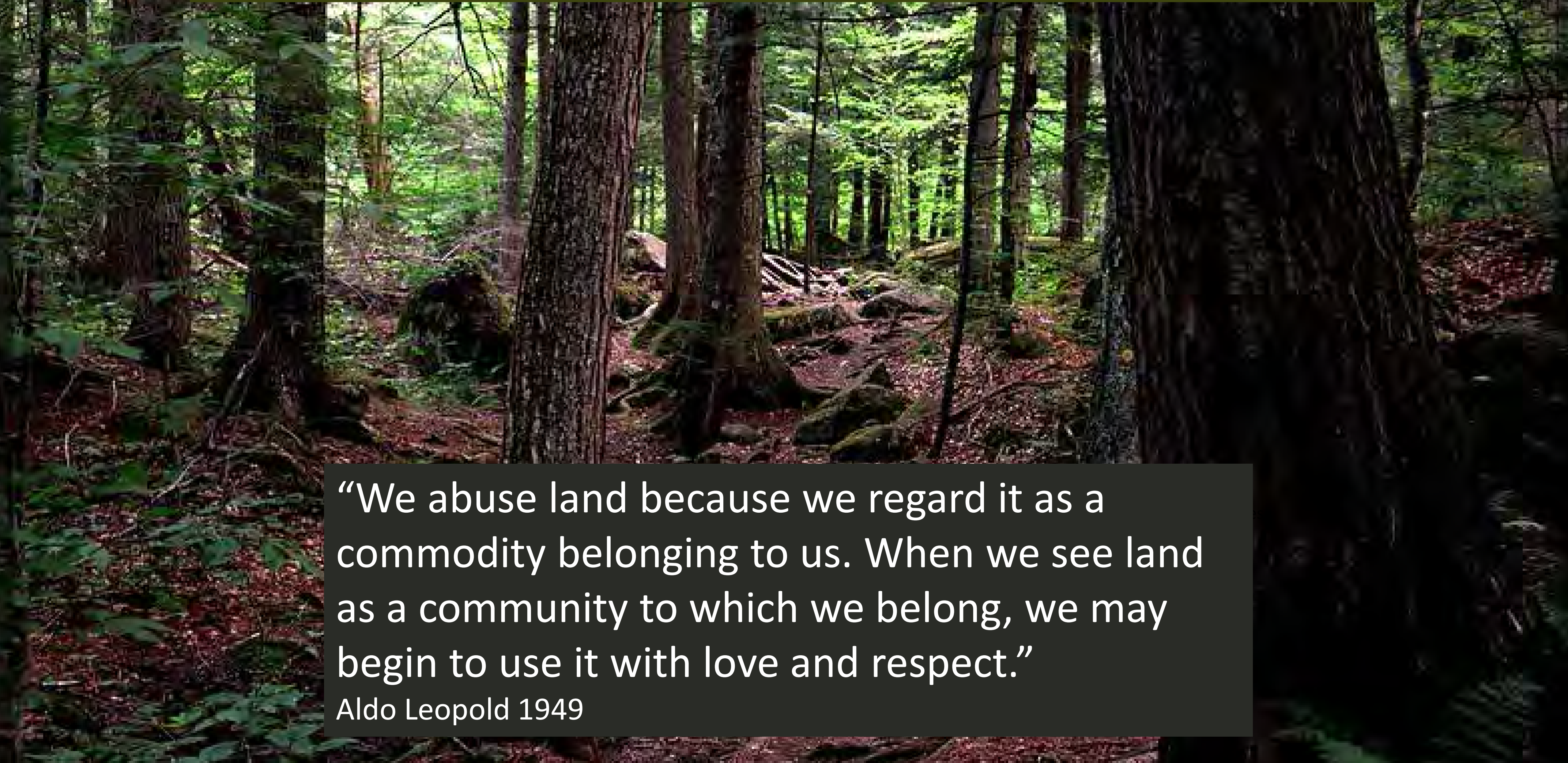
**Sustainably Managed Private Lands**

Promote best practices for biodiversity and carbon and clean water

Also

- Avoided conversion through good energy citing
- Grow/Harvest food sustainably
-

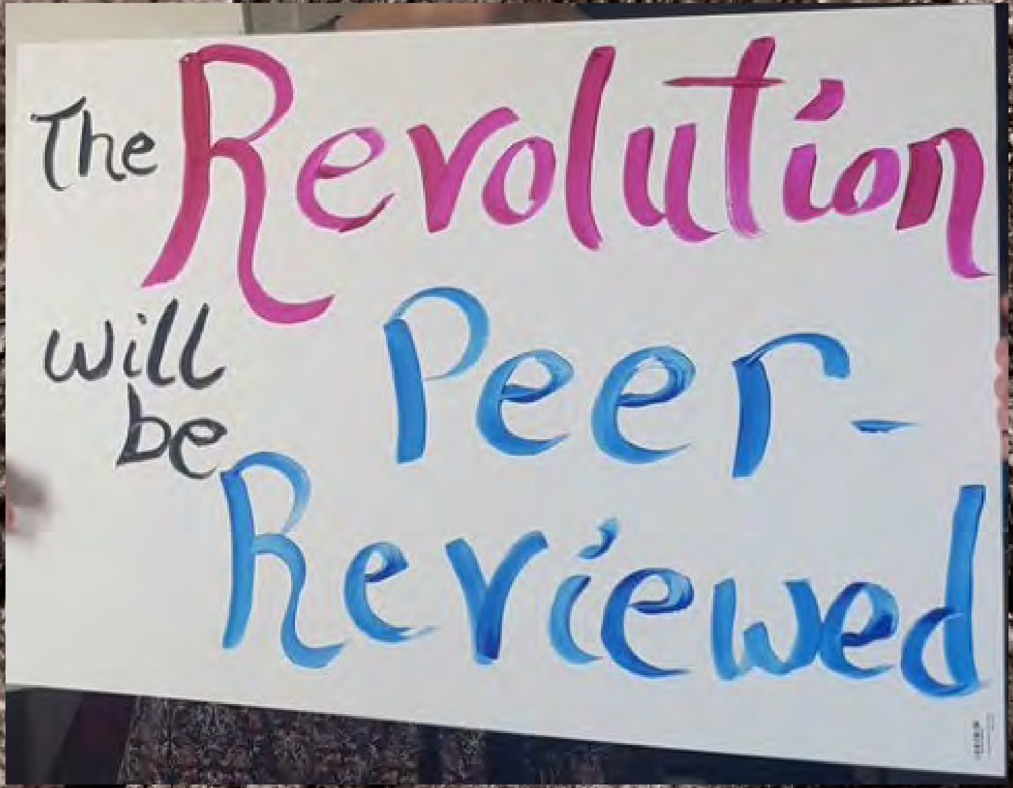
# A Reciprocal Partnership



"We abuse land because we regard it as a commodity belonging to us. When we see land as a community to which we belong, we may begin to use it with love and respect."

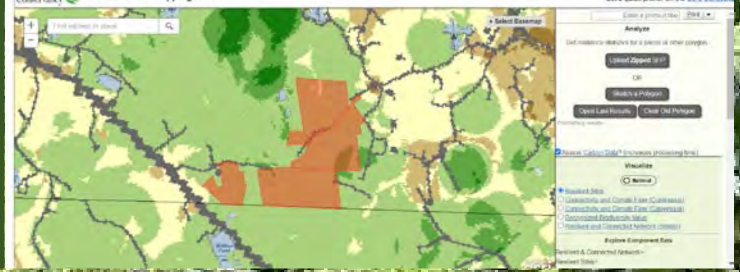
Aldo Leopold 1949

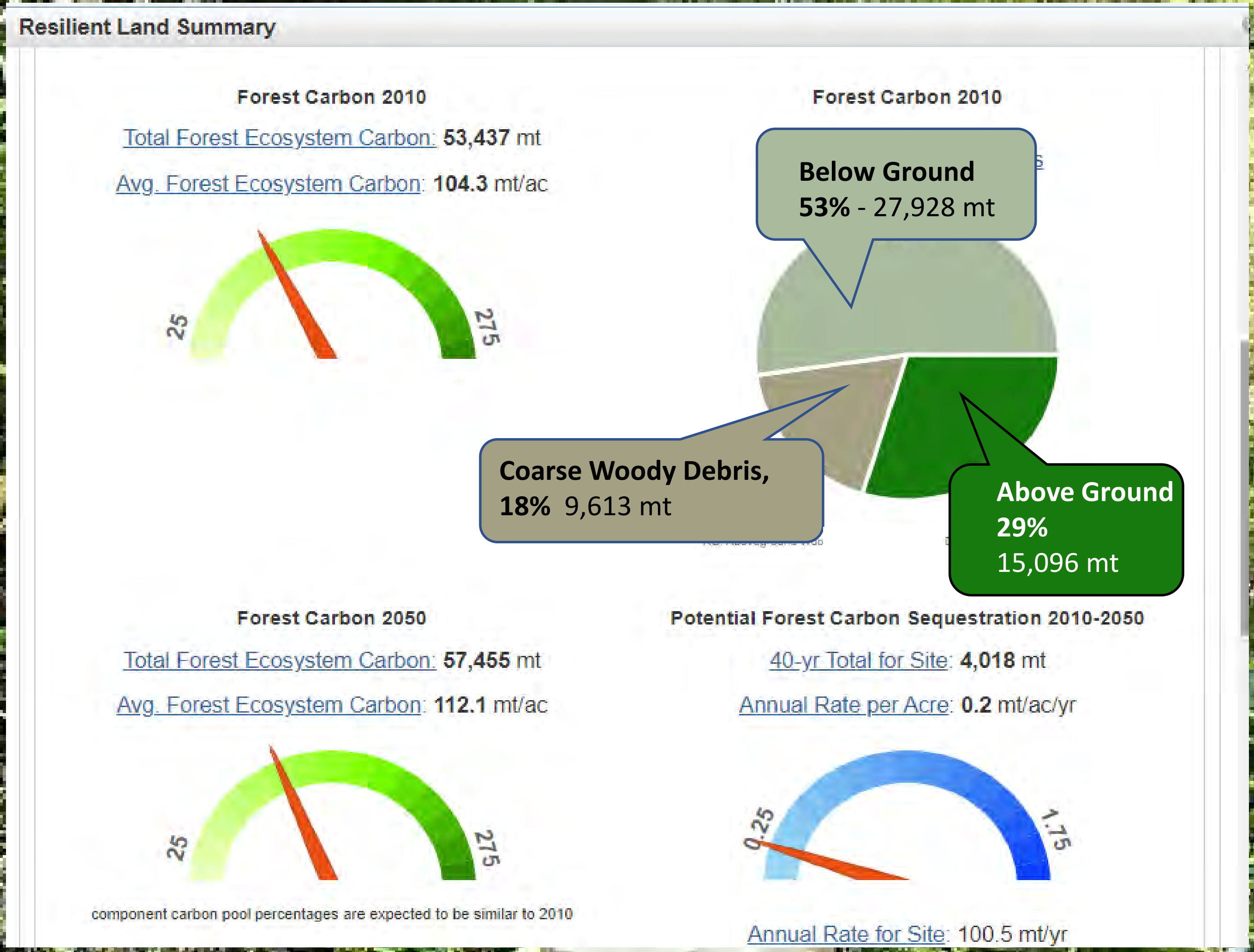
# Thank You!



# Binney Hill Wilderness Preserve

maps.tnc.org/resilientland






**514 Acres**

**2010 = 53,437** metric tons of C

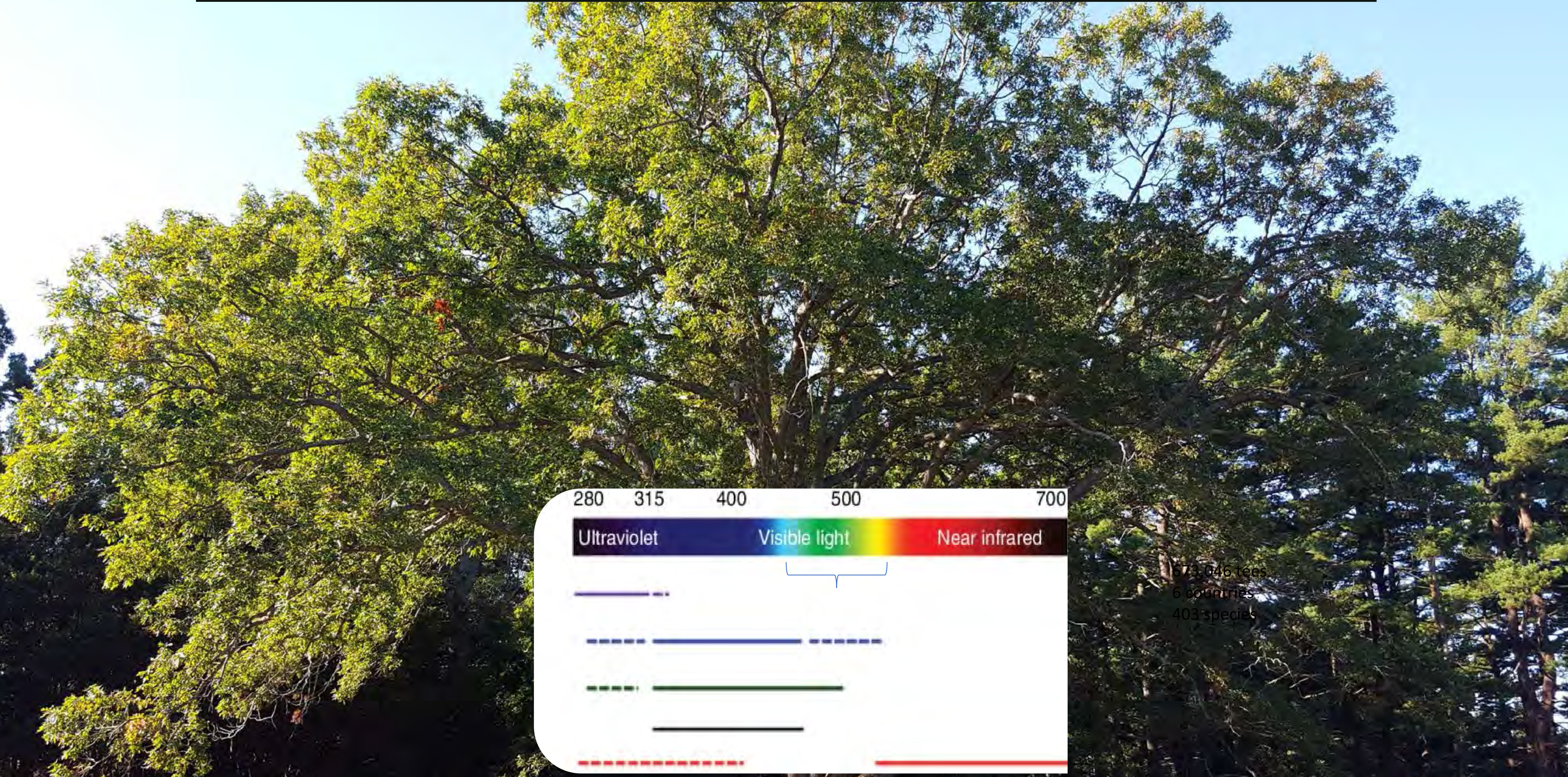
**2050 = 57,455** metric tons of C

40 yr. Seq = **4,018** metric tons of C

**Thank you**
Chris Williams
and
Natalia Hasler
of Clark University
for this amazing
data set!

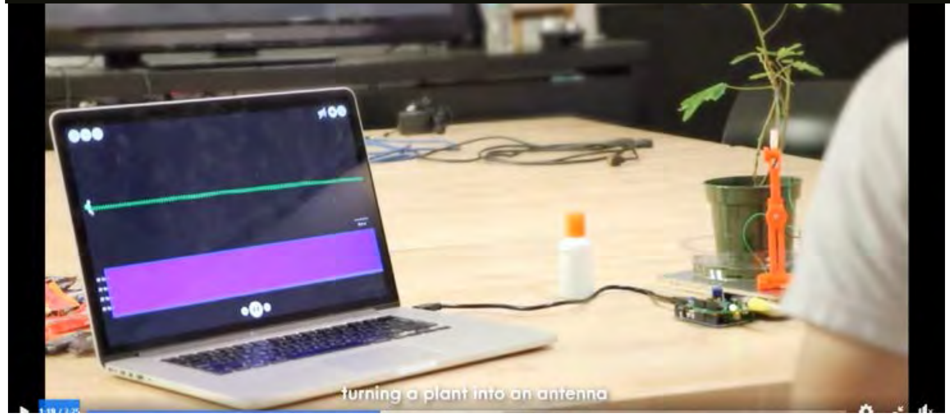
# Visual Monitoring

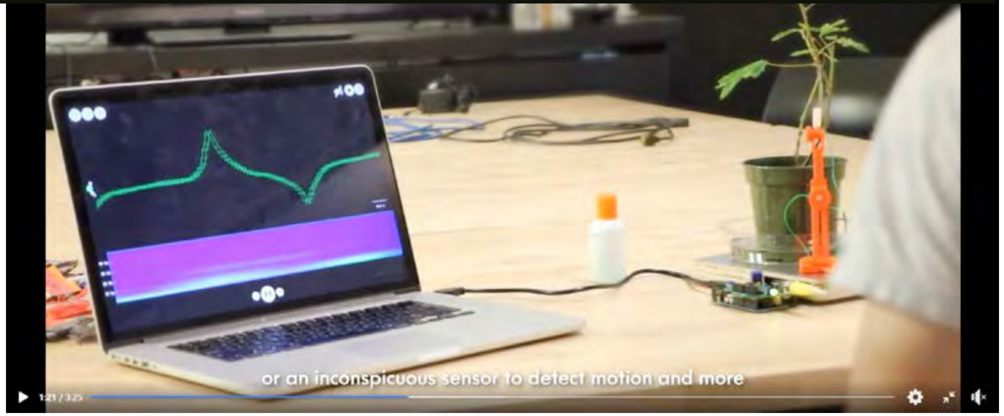
Does the tree know you are there?

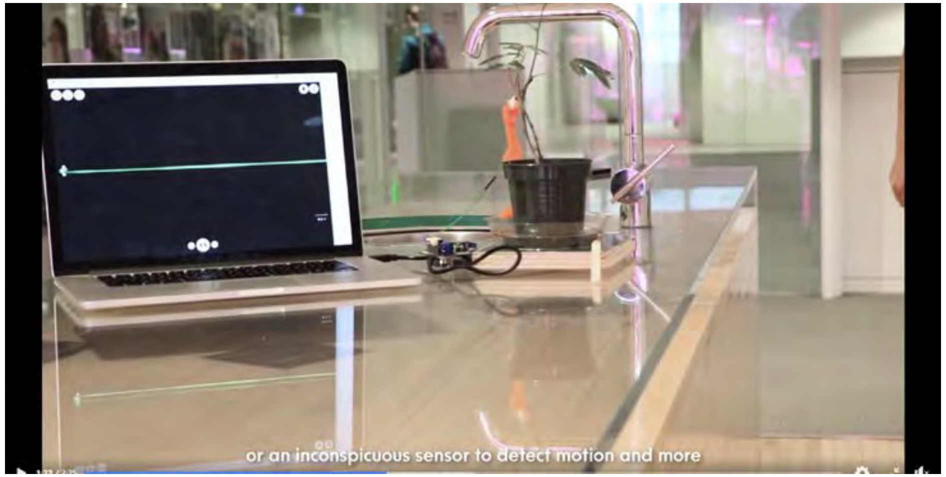


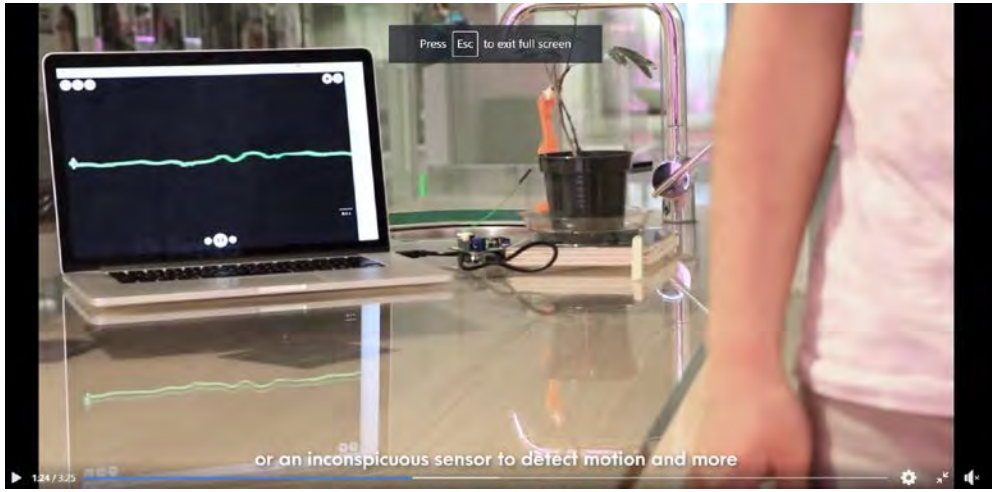

673,046 tees
6 countries
403 species

# Yes! Cyborg Botany

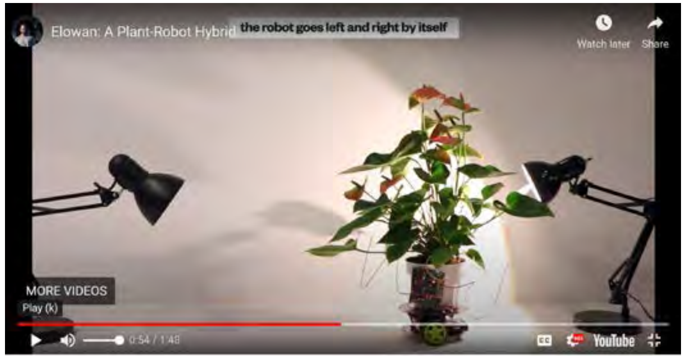


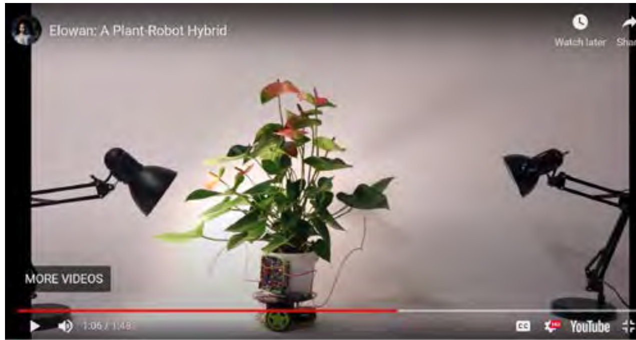



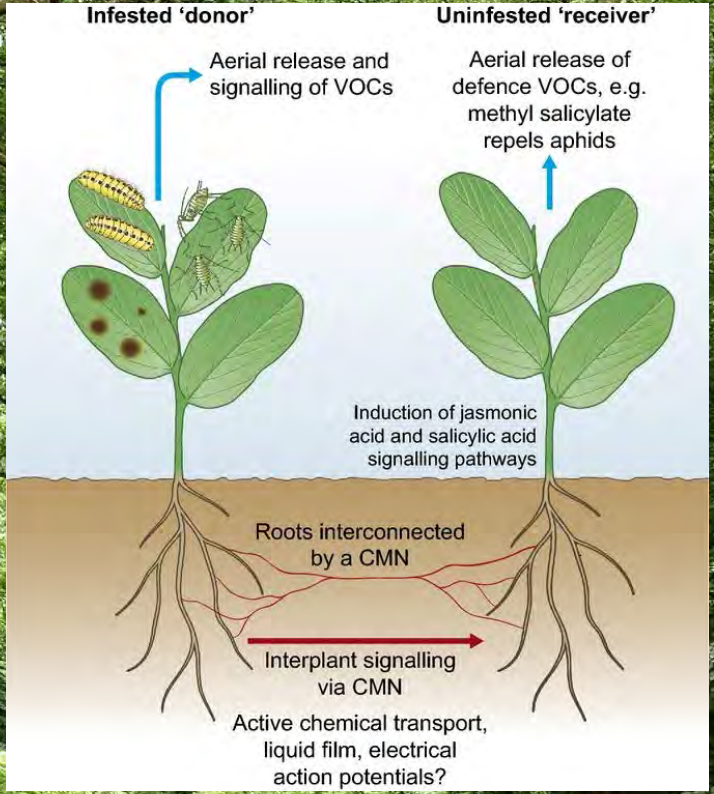




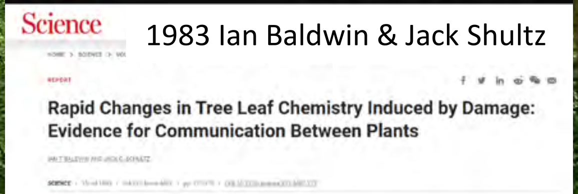



# Communication

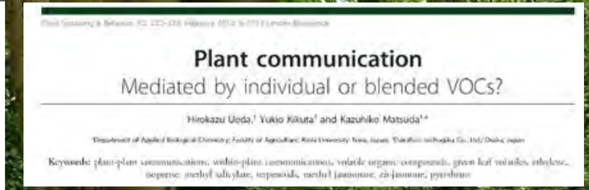
Volatile Organic Compounds


1983 Ian Baldwin & Jack Shultz


Science

Rapid Changes in Tree Leaf Chemistry Induced by Damage: Evidence for Communication Between Plants


Plant communication

Mediated by individual or blended VOCs?

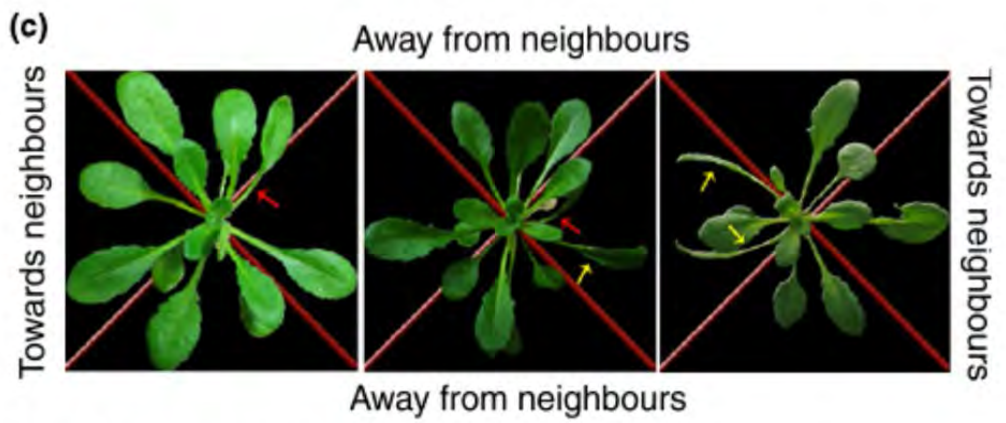



**Fig. 2** Arabidopsis plants reorient leaf growth in response to kin neighbours. (a) Time course of leaf-position ratio in rows formed by kin