The Irreplaceable Value of Mature Trees: Quantifying Cooling, Carbon Storage, and Sequestration Across Tree Sizes for Pinus ponderosa growing in California

CALCULATION REPORT

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Background

This report presents ecosystem services production equivalents, highlighting the volumes of selected ecosystem services provided by larger versus smaller trees. The purpose of this calculation is to illustrate a critical but often underappreciated reality: the number of smaller trees required to match the ecosystem services of a single large tree is substantial, though this number varies depending on the specific ecosystem service being assessed.

This comparative analysis was requested by Marily Woodhouse, Director of the Battle Creek Alliance in Manton, California, USA. The calculations draw upon the article *Leverett, R., Tuser, M. (2021). We Can't Plant Our Way Out of the Climate Crisis*. TREEIB.COM. LEDASCO s.r.o., accessible at https://www.treeib.com/carbon-storage-in-trees-robert-leverett. To ensure clarity and consistency, the analysis uses tree size data from the aforementioned article, which compares *Quercus rubra* (Northern Red Oak) trees. Additionally, calculations were performed for the "Big Pine" in Plumas National Forest, measuring 69.2 meters (227 feet) in height and 264 centimeters (104 inches) in diameter at breast height (DBH). This tree is referred as No. 1

Disclaimer

The presented calculations are based on modeled scenarios, as ecosystem service production varies significantly due to local environmental conditions. The i-Tree Eco software, used for this analysis, employs generalized data to estimate tree performance. For instance, carbon sequestration rates depend on the tree's growth rate, given that 50% of dry biomass is carbon. Trees growing in favorable conditions—such as those with ample water availability—may exhibit higher growth rates and consequently greater carbon sequestration than the generalized rates used by i-Tree Eco.

It is also important to note that carbon storage values in i-Tree Eco software are capped at 7,500 kg (or less, depending on the species). Beyond this cap, carbon storage increases at a species-specific rate of kg per centimeter of DBH growth. This limitation may influence the calculation for the "Big Pine," potentially underestimating its carbon storage.

The most precise way how to set a carbon stored weight is by measuring the tree with lidar followed by a standardized calculation method.

My field of work focuses on maximizing ecosystem service production from the mature trees we already have, as they are irreplaceable assets in our fight against climate change. By maintaining and enhancing the benefits these trees provide, I aim to contribute actionable strategies.

Methodology

The selected tree sizes (Figure 1) were entered into i-Tree Eco, which generated reports on ecosystem services. Three key ecosystem services were analyzed:

1. **Carbon Storage**
2. **Carbon Sequestration**
3. **Cooling Effect via Water Evapotranspiration Potential**

The cooling effect calculation is based on the energy required for water evapotranspiration. Specifically, the conversion of 1 gram of water from liquid to vapor requires 2.45 kJ of energy (equivalent to 1,054 British Thermal Units, BTU, at 20°C/68°F), which the tree absorbs from its surrounding environment. While these energy equivalents demonstrate the cooling potential of different tree sizes, comparing water volumes alone suffices for a direct comparison.

To determine replacement ratios, the ecosystem services provided by the largest tree were divided by the corresponding values for smaller trees. This ratio illustrates the number of smaller trees required to replicate the ecosystem services of a single large tree.

Species in the report: Pinus ponderosa growing in California

This is what I found online: Ponderosa pines (Pinus ponderosa) in California can attain impressive dimensions. Mature trees typically reach heights up to 50 meters (164 feet) and diameters at breast height (DBH) up to 150 centimeters (59 inches). Exceptional specimens have been recorded with heights up to 69 meters (226 feet) and DBHs up to 277 centimeters (109 inches).

https://www.conifers.org/pi/Pinus_ponderosa_ponderosa.php

The tallest known ponderosa pine, named "Phalanx," stands at 81.77 meters (268 feet) and is located in the Myers Creek drainage of the Rogue River–Siskiyou National Forest in Oregon.

https://en.wikipedia.org/wiki/List_of_tallest_trees

In California, the largest known ponderosa pine is the "Big Pine" in the Plumas National Forest, which measures 69.2 meters (227 feet) in height and 264 centimeters (104 inches) in DBH.

These measurements highlight the significant size that ponderosa pines can achieve under favorable conditions in California.

ANALYSIS RESULTS:

As expected, variability in the replacement ratios was observed after running the i-Tree analysis for specific ecosystem services, which is usual. Notably, the replacement ratios for annual carbon sequestration were unexpectedly low. These results align with the general underestimation of carbon sequestration observed across the entire i-Tree software suite—a point that has been raised by myself and other researchers. This issue is currently under discussion.

Carbon Storage Replacement Analysis (Figure 2)

1. **Tree No. 1 (DBH 104 inches):**
    - **Carbon Storage**: 16,534.7 lbs.
    - Replacement by smaller trees:
        - 2 trees of Tree No. 2 (DBH 53 inches).
        - 55 trees of Tree No. 3 (DBH 12 inches).
        - 266 trees of Tree No. 4 (DBH 6 inches).
        - 722 trees of Tree No. 5 (DBH 4 inches).
        - 3,674 trees of Tree No. 6 (DBH 2 inches).
        - 16,535 trees of Tree No. 7 (DBH 1 inch).
2. **Tree No. 2 (DBH 53 inches):**
    - **Carbon Storage**: 8,448.8 lbs.
    - Replacement by smaller trees:
        - 28 trees of Tree No. 3 (DBH 12 inches).
        - 136 trees of Tree No. 4 (DBH 6 inches).
        - 369 trees of Tree No. 5 (DBH 4 inches).
        - 1,878 trees of Tree No. 6 (DBH 2 inches).
        - 8,449 trees of Tree No. 7 (DBH 1 inch).

Annual Carbon Sequestration Replacement Analysis (Figure 3)

1. **Tree No. 1 (DBH 104 inches):**
    - **Carbon Sequestration**: 17.9 lbs/year.
    - Replacement by smaller trees:
        - 2 trees of Tree No. 2 (DBH 53 inches).
        - 4 trees of Tree No. 4 (DBH 6 inches).
        - 7 trees of Tree No. 5 (DBH 4 inches).
        - 18 trees of Tree No. 6 (DBH 2 inches).
        - 45 trees of Tree No. 7 (DBH 1 inch).
2. **Tree No. 2 (DBH 53 inches):**
    - **Carbon Sequestration**: 11.1 lbs/year.
    - Replacement by smaller trees:
        - 1 tree of Tree No. 3 (DBH 12 inches).
        - 2 trees of Tree No. 4 (DBH 6 inches).
        - 4 trees of Tree No. 5 (DBH 4 inches).

        - 11 trees of Tree No. 6 (DBH 2 inches).
        - 28 trees of Tree No. 7 (DBH 1 inch).

Cooling Effect Replacement Analysis (Figure 4)

Replacement of Tree No. 1:

- A large Ponderosa pine with DBH 104 inches provides a cooling effect of **57.94 GJ** annually.
- To replace its cooling effect:
    - **2 trees of No. 2 (DBH 53 inches)** are required.
    - **10 trees of No. 3 (DBH 12 inches)** are needed.
    - **35 trees of No. 4 (DBH 6 inches)** are needed.
    - **90 trees of No. 5 (DBH 4 inches)** are needed.
    - **314 trees of No. 6 (DBH 2 inches)** are needed.
    - **781 trees of No. 7 (DBH 1 inch)** are required.

Replacement of Tree No. 2:

- A medium-sized Ponderosa pine (DBH 53 inches) provides **24.32 GJ** of cooling annually.
- To replace its cooling effect:
    - **4 trees of No. 3 (DBH 12 inches)** are needed.
    - **15 trees of No. 4 (DBH 6 inches)** are needed.
    - **38 trees of No. 5 (DBH 4 inches)** are needed.
    - **132 trees of No. 6 (DBH 2 inches)** are required.
    - **328 trees of No. 7 (DBH 1 inch)** are required.

Summary of All Three Analyses

Key Insights Across Cooling, Carbon Storage, and Carbon Sequestration:

1. Large trees (DBH 104 inches) provide **disproportionate benefits**:
    - **Cooling Effect**: Equivalent to 781 smaller trees (DBH 1 inch).
    - **Carbon Storage**: Equivalent to 16,535 smaller trees (DBH 1 inch).
    - **Carbon Sequestration**: Equivalent to 45 smaller trees (DBH 1 inch).
2. Medium-sized trees (DBH 53 inches) require far fewer replacements but still emphasize the value of preserving mature trees:
    - **Cooling Effect**: Equivalent to 328 smaller trees (DBH 1 inch).
    - **Carbon Storage**: Equivalent to 8,449 smaller trees (DBH 1 inch).
    - **Carbon Sequestration**: Equivalent to 28 smaller trees (DBH 1 inch).
3. **Importance of Mature Trees**:

- Mature trees contribute significantly more to ecosystem services than younger, smaller trees.
- Planting small trees cannot replace the combined benefits of a single large tree within decades.

4. **Scientific Support**:
    - Studies like the one from *Frontiers in Forests and Global Change* (See citations below) reinforce the critical role of mature trees.
    - Larger trees store more carbon and provide exponentially greater ecological value.

Summary:

Large trees are irreplaceable ecological assets. A single mature tree provides cooling, carbon storage, and sequestration benefits unmatched by hundreds or even thousands of smaller trees. This underscores the urgency of conserving existing mature trees as they play a critical role in combating climate change and supporting urban ecosystems.

Studies from *Frontiers in Forests and Global Change* (see below) strongly back these findings, emphasizing the need to protect and prioritize mature trees in environmental planning and conservation. Conservation efforts must go beyond tree planting and focus on maintaining and protecting the invaluable services of these giants.

Large Trees Dominate Carbon Storage in Forests East of the Cascade Crest in the United States Pacific Northwest.

Large-diameter trees store disproportionally massive amounts of carbon and are a major driver of carbon cycle dynamics in forests worldwide. In the temperate forests of the western United States, proposed changes to Forest Plans would significantly weaken protections for a large portion of trees greater than 53 cm (21 inches) in diameter (herein referred to as "large-diameter trees") across 11.5 million acres (~4.7 million ha) of National Forest lands. This study is among the first to report how carbon storage in large trees and forest ecosystems would be affected by a proposed policy.

We examined the proportion of large-diameter trees on National Forest lands east of the Cascade Mountains crest in Oregon and Washington, their contribution to overall aboveground carbon (AGC) storage, and the potential reduction in carbon stocks resulting from widespread harvest. Analyzing forest inventory data from 3,335 plots, we found that large trees play a major role in the accumulated carbon stock of these forests. Tree AGC (kg) increases sharply with tree diameter at breast height (DBH; cm) among five dominant tree species.

Large trees accounted for 2.0 to 3.7% of all stems (DBH ≥ 1 inch or 2.54 cm) among five tree species but held 33 to 46% of the total AGC stored by each species. Pooled across the five dominant species, large trees accounted for 3% of the 636,520 trees occurring on the inventory plots but stored 42% of the total AGC. A recently proposed large-scale vegetation management project involving widespread harvest of large trees, mostly grand fir, would have removed ~44% of the AGC stored in these large-diameter trees, releasing a significant amount of carbon dioxide into the atmosphere.

Given the urgency of reducing atmospheric carbon and enhancing carbon accumulation to protect the climate system, it is prudent to continue protecting ecosystems with large trees for their carbon storage and co-benefits, including biodiversity habitats, resilience to drought and fire, and microclimate buffering under future climate extremes.

Mildrexler, D. J., Berner, L. T., Law, B. E., Birdsey, R. A., & Moomaw, W. R. (2020). Large Trees Dominate Carbon Storage in Forests East of the Cascade Crest in the United States Pacific Northwest. *Frontiers in Forests and Global Change, 3*.
https://doi.org/10.3389/ffgc.2020.594274

Older Eastern White Pine Trees and Stands Accumulate Carbon for Many Decades and Maximize Cumulative Carbon.

Pre-settlement New England was heavily forested, with trees exceeding 2 m in diameter. Since farm abandonment, the forests have regrown, representing one of the most successful regional reforestation efforts globally and forming part of the "Global Safety Net." Temperate "old-growth" forests and remnant stands demonstrate that native tree species can live for several hundred years, continuing to add to forest biomass and ecological complexity. Globally, forests are an essential natural climate solution, storing carbon and reducing annual increases in atmospheric CO_2 by approximately 30%.

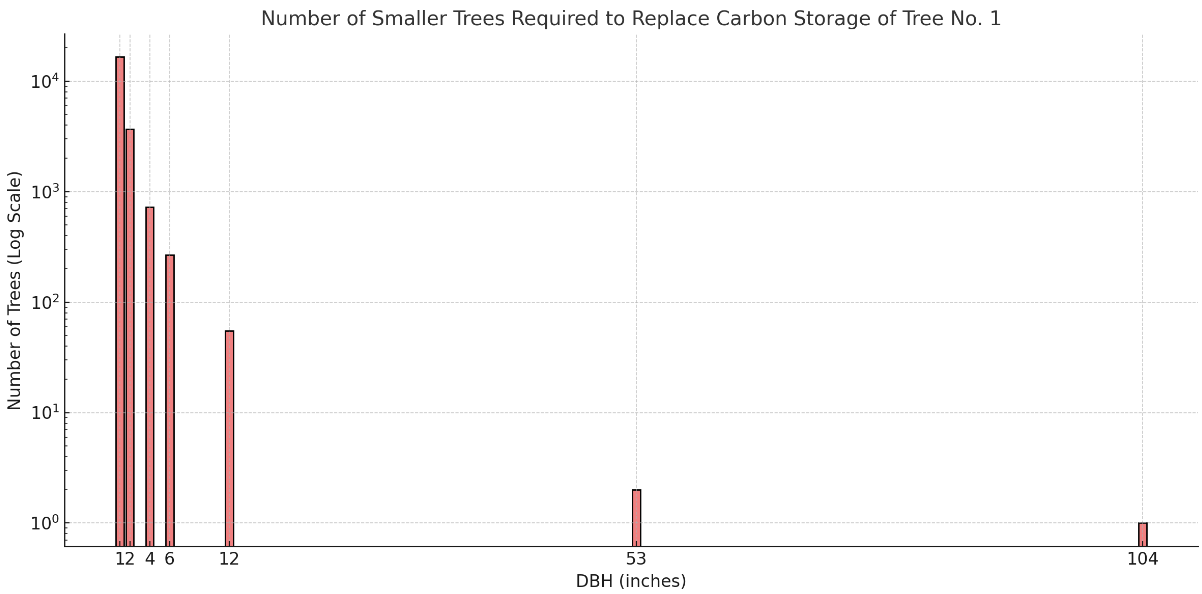
While some studies emphasize the rapid growth of young forests, others highlight the carbon storage and accumulation potential of older trees. Using long-term, accurate field measurements and volume modeling of eastern white pines (*Pinus strobus*) in New England, this study examined carbon accumulation beyond 80 years and compared results to U.S. Forest Service models. Key findings include:

1. Intact eastern white pine forests accumulate above-ground carbon at high rates even beyond 80 years and can double stored carbon over subsequent decades.
2. Large trees dominate above-ground carbon storage and continue accumulating carbon for well over 150 years.
3. Productive stands maintain high carbon accumulation rates in live trees over long periods.

Given the urgency of addressing the climate emergency, maintaining and enhancing carbon in existing forests—proforestation—emerges as a powerful regional climate solution. New England forests, most of which are less than 100 years old, have tremendous potential for growth. Dedicating some forests to proforestation will produce large, carbon-dense trees while safeguarding biodiversity, special habitats, and ecosystem integrity. Strategically growing and protecting these forests represents a proven, low-cost natural climate solution with long-term benefits for biodiversity and climate mitigation.

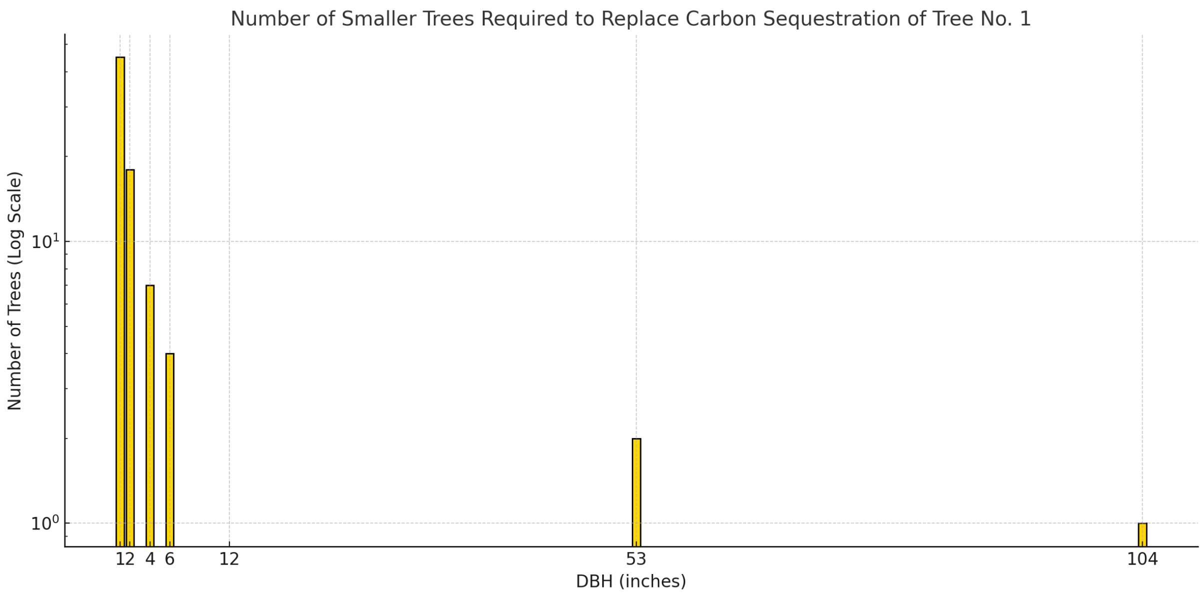
Leverett, R. T., Masino, S. A., & Moomaw, W. R. (2021). Older Eastern White Pine Trees and Stands Accumulate Carbon for Many Decades and Maximize Cumulative Carbon. *Frontiers in Forests and Global Change, 4*. https://doi.org/10.3389/ffgc.2021.620450

Graphical representation of the results:



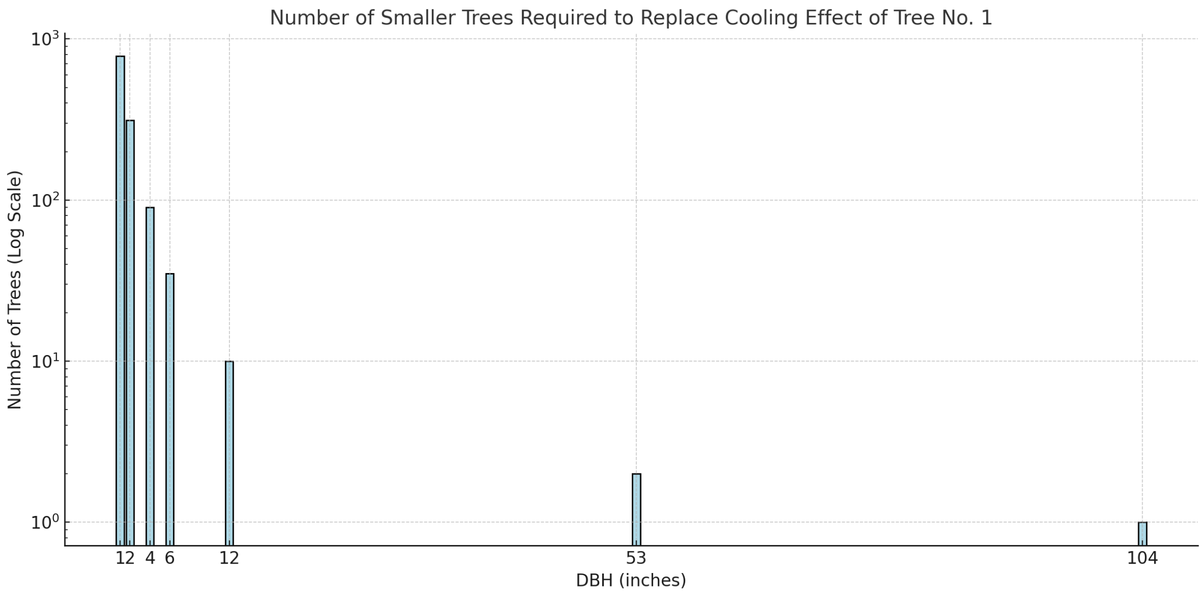
Carbon Storage Replacement:

- This chart shows how many smaller trees are needed to replace the carbon storage of a large tree. For example, replacing the carbon storage of a single large tree (DBH 104 inches) requires over 16,500 trees with DBH 1 inch.



Carbon Sequestration Replacement:

- The chart focuses on annual carbon sequestration. To replace the carbon sequestration of one large tree (DBH 104 inches), 45 trees with DBH 1 inch are needed, emphasizing the inefficiency of substituting large trees with smaller ones.



Cooling Effect Replacement:

- The chart highlights the number of smaller trees required to replace the cooling effect of a single large tree (DBH 104 inches). Larger trees provide significantly more cooling, with 781 trees of DBH 1 inch needed to match one large tree.

Figure 1

1	Ponderosa pine	104	227
2	Ponderosa pine	53	100
3	Ponderosa pine	12	50
4	Ponderosa pine	6	40
5	Ponderosa pine	4	25
6	Ponderosa pine	2	10
7	Ponderosa pine	1	4,5

(Figure 2)

Carbon storage replacement

Tree No.	Species	DBH / inch	Heigh / feet	Carbon storage lb	replacement of No 2	replacement of No 1
1	Ponderosa pine	104	227	16534,7		1
2	Ponderosa pine	53	100	8448,8	1	2
3	Ponderosa pine	12	50	302,2	28	55
4	Ponderosa pine	6	40	62,1	136	266
5	Ponderosa pine	4	25	22,9	369	722
6	Ponderosa pine	2	10	4,5	1 878	3 674
7	Ponderosa pine	1	4,5	1	8 449	16 535

Due to limits of available models, i-Tree Eco will limit carbon storage to a maximum of 7,500 kg (16,534.7 lbs) and not estimate additional storage for any tree beyond a diameter of 254 cm (100 in). Whichever limit results in lower carbon storage is used.

(Figure 3)

Annual Carbon Sequestration replacement

Tree No.	Species	DBH / inch	Heigh / feet	Carbon seq. lb	replacement of No 2	replacement of No 1
1	Ponderosa pine	104	227	17,9		1
2	Ponderosa pine	53	100	11,1	1	2
3	Ponderosa pine	12	50	11,9	1	2
4	Ponderosa pine	6	40	4,8	2	4
5	Ponderosa pine	4	25	2,7	4	7
6	Ponderosa pine	2	10	1	11	18
7	Ponderosa pine	1	4,5	0,4	28	45

(Figure 4)

Cooling effect replacement

Tree No.	Species	DBH / inch	Heigh / feet	Leaf Area (ft²)	Potential Evapotranspiration / (gal/yr)	Potential Evaporation / (g/yr)	Potential Ev. Cooling GJ	replacement of No 2	replacement of No 1
1	Ponderosa pine	104	227	25046	6247,5	23 649 360,10	57,941		1
2	Ponderosa pine	53	100	10511	2621,9	9 924 971,15	24,316	1	2
3	Ponderosa pine	12	50	2625,7	655	2 479 444,72	6,075	4	10
4	Ponderosa pine	6	40	708,5	176,7	668 882,26	1,639	15	35
5	Ponderosa pine	4	25	279,3	69,7	263 843,20	0,646	38	90
6	Ponderosa pine	2	10	79,9	19,9	75 329,69	0,185	132	314
7	Ponderosa pine	1	4,5	31,9	8	30 283,29	0,074	328	781