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Effects of Stand Age on Aboveground Live Tree Carbon Stock and Change in Forests

The role of forests in the global carbon cycle and opportunities to use natural climate solutions to mitigate greenhouse gas emissions have gained attention for a number of reasons including the Trillion Trees Initiative, California's cap and trade legislation, corporate net-zero pledges, and recent federal and state policy initiatives. Forest carbon sequestration is an essential part of natural climate solutions, and understanding the dynamics of carbon sequestration is crucial for developing guidelines to manage forest carbon sinks.

In this recently released publication, Coeli Hoover and James Smith, scientists with the U.S. Department of Agriculture (USDA), Forest Service's Northern Research Station, provide an overview of forest carbon sequestration in the conterminous United States (48 adjoining states, not including Alaska and Hawaii). Their work focuses on forest carbon stocks and rates of change in different age classes and geographic regions. The authors also explore the role of older versus younger forests in carbon storage and highlight the importance of considering both stocks and rates when developing or assessing forest carbon.

Many factors including climate, site productivity, species mix, age class distribution, stocking level, and management and disturbance

KEY MANAGEMENT CONSIDERATIONS

- Regional carbon stock: The average aboveground live tree carbon stock ranges from 11.6 to 130 metric tons of carbon per hectare across different regions of the United States. Carbon density generally increases with age class, highlighting the importance of maintaining a range of age classes across the landscape.
- Regional carbon change rate: The rate of carbon accumulation varies across regions and age classes, with higher rates typically observed in younger stands. Accumulation rates generally decline as stands age.
- State-level carbon stock: Carbon density varies among states, but the pattern of increasing carbon density with age class remains consistent.
- State-level carbon change rate: Carbon accumulation rates differ by state and age class, following the general trend of decreasing rates with increasing stand age.
- Effective forest management strategies can optimize carbon storage while addressing other objectives, such as reducing wildfire risk, preserving ecosystem services, and promoting sustainable timber production.

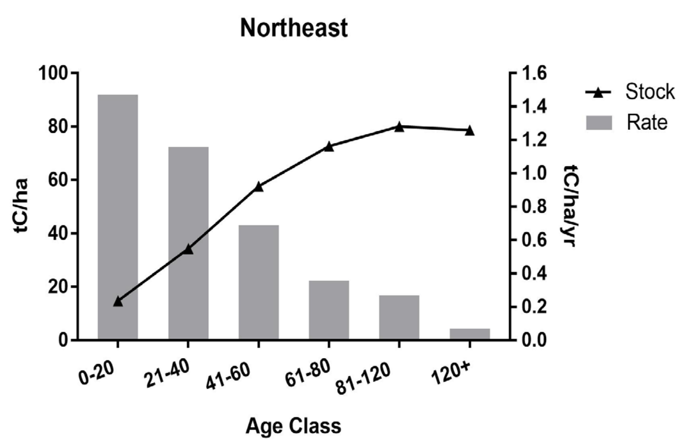
Old growth beech-hemlock stand (left) and young stand regenerating after a stand replacing tornado (right) located in the Tionesta Scenic and Research Natural Area, Allegheny National Forest. Prior to disturbance, the young forest looked like the old growth stand. USDA Forest Service photos by Coeli Hoover.

history influence forest carbon stocks and carbon accumulation rates. In the past, the use of varying terminology and different approaches to studying forest carbon has contributed to an incomplete understanding of carbon sequestration and the role of older versus younger forests in carbon accumulation. The choice of metrics and inconsistent use of terms in these studies further contributes to the variation in results. However, summarizing forest carbon as both stock and change can provide valuable information for natural resource managers, private landowners, and other individuals who make and influence land management decisions.

Understanding Carbon Stocks and Rates of Change

A full understanding of forest carbon dynamics requires considering both carbon stocks and rates of change. Carbon stock refers to the amount of carbon in live aboveground tree biomass at a specific point in time, often expressed as carbon density (tonnes of carbon per hectare [tC/ha]). Carbon accumulation rate represents the net change in carbon stock over time and is generally expressed on an annual basis (tonnes of carbon per hectare per year [tC/ha/yr]). By examining both carbon stock and rate, forest managers can assess tradeoffs among different management objectives, beyond carbon sequestration alone.

The forest inventory data used in Hoover and Smith's analyses are collected by the Forest Inventory and Analysis (FIA) program of the USDA Forest Service. The FIA Database (FIADB) provides publicly available data on many forest attributes, including carbon stock. Data summarized at the state and regional scale offer accessible information for forest managers and policymakers.



Carbon stock (tonnes of carbon per hectare [tC/ha]) and rate (tonnes of carbon per hectare per year [tC/ha/yr]) by age class (years) for Northeast forests. Forests in the Northern Lake States and Central States regions show similar patterns. See Tables 1 and 2 for data by region and a list of states in each region.

Hoover and Smith's findings show that carbon density increases with age class in all regions, although in some regions it declines in the oldest age class. The average annual change, or the rate of carbon accumulation, generally declines with age, with some variations among the regions (often due to harvesting or natural disturbance). While multiple factors, including site productivity, age class distribution, management activities, and disturbance regimes, influence carbon stock and accumulation rates, patterns are similar for both hardwoods and softwood forest cover types.

Forest age class plays a key role in carbon storage, so understanding the distribution of age classes is vital for predicting future carbon stocks. Because younger stands often have higher accumulation rates, it is important to maintain a range of age classes across the landscape. Knowing how age classes are distributed across the forest can help forest managers estimate live tree carbon and make informed decisions about the carbon consequences of forest management objectives.

The researchers highlight the importance of considering both standing carbon stocks and average annual change of carbon storage. Hoover states, "With the increased focus on natural climate solutions and the need to evaluate tradeoffs between forest carbon and more traditional management objectives, easily accessible information on stocks and rates is an important resource for guiding land management plans and assessments of future forest carbon storage." By examining forest carbon at the regional and state levels, individuals who make and influence forest management decisions can gain valuable insights into current and potential forest carbon storage. Hoover offers that effective forest management strategies can balance carbon sequestration with other objectives, such as reducing wildfire risk, preserving ecosystem services, and promoting sustainable timber production.

Project Lead

Coeli Hoover is a research ecologist with with the Climate and Carbon Cycle Sciences research work unit and is based in Durham, New Hampshire. Learn more about her work at: https://www.fs.usda.gov/research/about/people/choover.

James Smith is a research plant physiologist with the Forest Inventory and Analysis program and is based in Durham, New Hampshire. Learn more about his work at: https://www.fs.usda.gov/research/about/people/jsmith11.

FURTHER READING

Hoover, Coeli M.; Smith, James E. 2023. Aboveground live tree carbon stock and change in forests of conterminous United States: influence of stand age. Carbon Balance and Management. 18(1): 7. 11 p. https://doi.org/10.1186/s13021-023-00227-z.

Table 1.—Carbon density (tonnes C/hectare [tC/ha]) estimates for aboveground live tree carbon by region and age class

Region[a]	Age class (years)	Mean carbon density (tC/ha)	SEM[b]	Forest area (kha)	Area of forestland (percent)
Northeast	0-20	15.5	0.8	1,361	4
	21–40	34.8	0.6	3,513	10
	41–60	59	0.6	6,437	19
	61–80	77.1	0.5	10,445	31
	81–120	88.4	0.5	11,464	34
	121+	88.6	2.1	783	2
	Overall	70.9	0.3		
Northern Lake States	0–20	11.5	0.3	2,704	12
	21–40	29.1	0.4	3,219	15
	41–60	42	0.5	4,576	21
	61–80	52.4	0.4	5,977	27
	81–120	60.6	0.5	5,167	23
	121+	58	1.9	535	2
	Overall	43.9	0.2		
Central States	0–20	14.1	0.9	697	5
	21–40	36.9	0.8	1,473	10
	41–60	54.4	0.6	3,881	27
	61–80	63.1	0.6	4,769	33
	81–120	70.9	0.8	3,350	23
	121+	76.7	3.6	258	2
	Overall	57.7	0.4		

Note: To convert metric tons per hectare to tons per acre, multiply by 0.446.
[a]Northeast States: CT, DE, MA, MD, ME, NH, NJ, NY, PA, RI, WV; Northern Lake States: MI, MN, WI; Central States: IA, IL, IN, MO, OH.
[b]SEM = standard error of the mean.

Table 2.— Carbon accumulation rate (tonnes carbon/hectare/year [tC/ha/yr]) estimates for aboveground live tree carbon by region and age class

Region[a]	Age class (years)	Average rate (tC/ha/yr)	N[b]
Northeast	0–20	1.47	425
	21–40	1.16	897
	41–60	0.69	1823
	61–80	0.36	2782
	81–120	0.27	2083
	120+	0.07	136
	Overall	0.55	
Northern Lake States	0–20	1.13	946
	21–40	0.82	1221
	41–60	0.26	2008
	61–80	0.14	2392
	81–120	0.16	1343
	120+	0.41	184
	Overall	0.40	
Central States	0–20	1.17	152
	21–40	0.97	490
	41–60	0.39	1058
	61–80	0.18	1025
	81–120	0.07	551
	120+	−0.49	47
	Overall	0.38	

Note: To convert metric tons per hectare to tons per acre, multiply by 0.446.

[a]Northeast States: CT, DE, MA, MD, ME, NH, NJ, NY, PA, RI, WV; Northern Lake States: MI, MN, WI; Central States: IA, IL, IN, MO, OH.

[b]N = number of paired plots on which the estimate is based.