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INSIDE

"Science affects the way we think together."
Lewis Thomas

Forestry as a Natural Climate Solution: The Positive Outcomes of Negative Carbon Emissions

David D'Amore

An unthinned, even-aged stand in southeast Alaska. New research on carbon sequestration in the region's coastal temperate rainforests, and how this may change over the next 80 years, is helping land managers evaluate tradeoffs among management options.

IN SUMMARY

Forests are considered a natural solution for mitigating climate change because they absorb and store atmospheric carbon. With Alaska boasting 129 million acres of forest, this state can play a crucial role as a carbon sink for the United States. Until recently, the volume of carbon stored in Alaska's forests was unknown, as was their future carbon sequestration capacity.

In 2007, Congress passed the Energy Independence and Security Act that directed the Department of the Interior to assess the stock and flow of carbon in all the lands and waters of the United States. In 2012, a team composed of researchers with the U.S. Geological Survey, U.S. Forest Service, and the University of Alaska assessed how much carbon Alaska's forests can sequester.

The researchers concluded that ecosystems of Alaska could be a substantial carbon sink. Carbon sequestration is estimated at 22.5 to 70.0 teragrams (Tg) of carbon per year over the remainder of this century. In particular, Alaska's dense coastal temperate forests and soils are estimated to sequester 3.4 to 7.8 Tg of carbon per year. Forest management activities were found to have long-term effects on the maximum amount of carbon a site can sequester. These findings helped inform the carbon assessment sections of Chugach and Tongass National Forests' land management plans.

"Stones have been known to move and trees to speak."
— William Shakespeare

Forests have long been recognized for the ecological and economic services they provide. The Organic Administration Act of 1897 that authorized the creation of forest reserves, now better known as national forests, describes these forest reserves as securing "favorable conditions of water flows, and to furnish a continuous supply of timber." As efforts to mitigate climate change gain traction, forests are being appreciated for the role they play in the global carbon cycle. Through photosynthesis, trees convert sunlight, water, and atmospheric carbon dioxide into carbohydrates (energy) and oxygen. These carbohydrates contain carbon that is fixed from atmospheric carbon dioxide. This carbon is used to create woody tissue and other plant parts and is stored in these woody tissues or sequestered in its roots and soil.

Although a tree releases carbon dioxide, along with heat and excess water when consuming carbohydrates, more carbon is stored than is released into the atmosphere. This ability to sequester carbon is one reason forests are considered a natural solution to help mitigate climate change. By sequestering carbon, forests are offsetting the emissions that human activity is releasing into the atmosphere.

However, forests release carbon too; it doesn't remain permanently sequestered. Decomposition of biomass stored in trees and soil releases carbon to the atmosphere. A portion of this carbon mixes with water and travels underground until reaching a water source that carries it to a river and out to the ocean. Once in the ocean, this carbon can fuel marine life, get jettisoned back into the atmosphere by a breaking wave, or sink to the deep ocean and remain there for millennia.

Research over the past decade has answered questions about the rates at which trees of different ages and forests of different types sequester carbon. We now know that middle-aged forests (about 50 to 100 years old) sequester carbon at a faster rate than older forests, but older forests store more carbon because over time, they have sequestered more carbon into the trees and soils. Management activities and natural disturbances also affect the volume of carbon sequestered in a forest. When trees are harvested, the disturbed soil releases carbon to the atmosphere. Regenerating small young trees won't immediately store as much carbon as the larger, older harvested trees did. Similarly, a bark beetle outbreak or wildfire can result in dying trees releasing carbon into the atmosphere and a decrease in carbon being stored on the landscape.

Why is it necessary to understand the carbon cycle at this fine level of detail? The United Nations Framework on Climate Change, which was passed in 1992, seeks to stabilize the concentration of greenhouse gasses, such as carbon dioxide, in the atmosphere. The United States is a signatory to the agreement, and the Environmental Protection Agency is charged with compiling an annual report on the nation's annual carbon flux or carbon budget: the volume of carbon released into the atmosphere minus the volume of carbon sequestered by landscapes.

KEY FINDINGS

- Alaska's temperate coastal forests absorb more carbon from the atmosphere than they release. They function as carbon "sinks" in part because cool temperatures slow decomposition and lead to an accumulation of carbon in woody debris and soils.
- The amount of carbon sequestered by Alaska ecosystems is projected to increase by 22.5 to 70.0 teragrams of carbon per year over the remainder of this century. This increase is in part due to vegetation growth in the temperate forests in the southeast portion of the state.
- Young-growth forests rapidly accumulate carbon, making them carbon hotspots and a focus for management initiatives. Precommercial thinning, however, reduces the maximum amount of carbon stored on a site. This reduction may persist 100 years after treatment.
- Soils in the coastal temperate rainforest store large amounts of carbon, estimated at 4.5 petagrams of carbon, which is even more than the vast aboveground pools. However, soil carbon storage is susceptible to a warming climate; warmer temperatures could increase biomass accumulation while also increasing decomposition.

Tracking Carbon Through Forests and Streams

With Alaska's 129 million acres of forest, the state plays a crucial role in the global carbon cycle. The coastal temperate rainforests in southeast and south-central Alaska are particularly valuable as carbon sinks because they grow rapidly and do not experience frequent disturbances, such as wildfire or bark beetle outbreaks. Dave D'Amore, a research soil scientist with the U.S. Forest Service Pacific Northwest Research Station, focuses on understanding the carbon cycle, specifically, within the terrestrial landscapes in southeast Alaska.

Maintaining this research focus over the past 25 years hasn't always been easy, D'Amore admits. "Carbon cycle science wasn't a high priority for research in the past because you have to balance work related to current research questions with work addressing

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A thinned, 50-year-old stand in southeast Alaska. Thinning enables more sunlight to reach the forest floor, resulting in a more diverse understory and wildlife habitat, and increases growth rate of remaining trees. In a forest model simulation, the volume of carbon stored aboveground in a thinned stand was less than in an unthinned stand 100 years after treatment.

potential future needs and questions," he explains. "It is often difficult to anticipate future information needs and initiate research in advance of their importance"

Now, however, carbon cycle research is a priority, and according to D'Amore, "it's an important research issue worldwide."

In 2001, D'Amore and his colleagues realized that basic knowledge was needed on how dissolved organic carbon moved through southeast Alaska's watersheds. "We recognized that the lateral flux could be a big part of the carbon budget," he says. "We lose a portion of the carbon by a pathway that wasn't accounted for traditionally in carbon balance equations."

Carbon is a fundamental component of organic acids, which influence aquatic productivity as a source of nutrients and energy. The high volume of rainfall and perennial streamflow that is common in coastal forests carries large amounts of carbon from the soil and into the streams. "These streams are dark brown because they're chock-full of organic carbon," D'Amore explains.

After publishing several papers on carbon cycling and confirming that there is a significant volume of carbon leaving watersheds through aquatic pathways, D'Amore shifted his focus to the terrestrial side of the carbon cycle. He wanted to pursue both the basic questions and the applied questions that forest managers needed answered. Specifically, on the Tongass National Forest, management was transitioning from harvesting old-growth stands to young-growth stands. "A key question was how much carbon is accumulating in those young stands and what happens when you thin them?" D'Amore says.

The accepted belief among land managers was that thinning young stands, which was done to increase the growth rate of the remaining trees and improve wildlife habitat, increased carbon sequestration. D'Amore recalls thinking, "No, I don't think it works that way."

To test this hypothesis, D'Amore's team used two datasets containing growth-and-yield measurements of young-growth forests in southeast Alaska. One dataset dating back to the 1920s included measurements of 12 unthinned plots, while the other dataset contained measurements from 272 thinned and unthinned plots. The scientists used these data to build a forest model that simulated carbon storage and accumulation over 100 years across three different thinning treatments (a 47, 60, and 73 percent reduction in basal area) and a nonthinned treatment. The model was run through 100 years because that was the timespan of the observations.

The results revealed that thinning the forest reduced the overall volume of carbon being sequestered—100 years later, a thinned stand did not achieve the same volume of sequestered carbon as an unthinned stand. However, the rate of carbon accumulation in the thinned stands was similar to that of the unthinned stands if decomposition of cut trees in the thinned stands was not included in the equation.

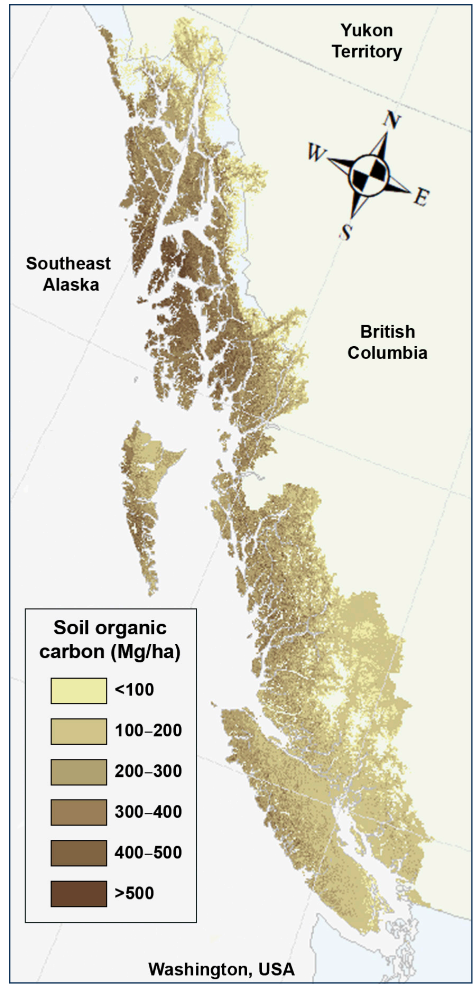
While the findings validated D'Amore's hunch, he cautions that these results don't suggest that reducing the carbon sequestering potential of a forest is good or bad. "We're just answering a key question related to the carbon cycle so managers can make a more informed decision," he explains. "There might be another reason for thinning, such as to enhance wildlife habitat, and there is a value judgement that needs to be made. There are a lot of tradeoffs."

Mapping Carbon in Soil

With the role of the aboveground forests in the carbon cycle quantified, the next piece was quantifying the volume stored in the soil across the region. A regional map of soil-stored carbon is needed, says D'Amore, because "soil has traditionally not been included in carbon budget calculations because people view soil as stable and not changing very fast. Yet small changes over large areas, or even short periods of time, can impact the carbon budget."

To create this map, D'Amore collaborated with colleagues throughout Alaska and British Columbia. Gavin McNicol led the research team as a postdoctorate with the Alaska Coastal Rainforest Center—a hub of collaborative research founded by the University of Alaska Southeast and U.S. Forest Service.

A researcher collects soil samples from volcanic-derived soil in the Heén Latinee Experimental Forest within the Tongass National Forest. These samples were later analyzed to determine the carbon content.



Soil organic carbon stock predictions to 1 m (Mg C ha−1) at 90.5 m resolution for small watersheds within coastal temperate rainforest across British Columbia and southeast Alaska. This effort to map soil carbon revealed that an estimated 22 percent of carbon in this coastal temperate rainforest is stored in the top 1 m of soil. Adapted from McNicol et al. (2019).

McNicol employed a new technique called digital soil mapping. He created a model that used data collected from 800 plots spanning from southeast Alaska to Vancouver Island to estimate the soil carbon stored in areas without plot data. With the compiled soil database, McNicol used measurements such as the amount of rainfall, temperature, topography, and other variables to predict soil type at the local level as these factors can affect the amount of carbon that soils sequester.

The modeling effort provided maps of regional carbon patterns, and estimated the total carbon stored within the coastal forest region at 4.5 petagrams—about 4.5 billion tons, or 2.2 trillion pounds—with 22 percent of the carbon stored in the organic soil layers.

"McNicol's work is a model-based estimate," cautions D'Amore. "But there's a lot more confidence in the estimated carbon values because of the large amount of information that was used to predict the stock at each location."

Alaska Land Carbon Project

In 2013, D'Amore received a message from A. David McGuire, an ecologist with the U.S. Geological Survey (USGS) stationed at the University of Alaska in the Cooperative Fish and Wildlife Research Unit. McGuire was the lead scientist charged with overseeing the Alaska Carbon Cycle Assessment. In 2007, President George W. Bush signed the Energy Independence and Security Act, which mandated that the Department of the Interior conduct an assessment on the potential for ecosystems in the United States to sequester carbon. The USGS was assigned the task of conducting the nationwide assessment. After conducting assessments for the regions in the lower 48 states, it was Hawaii and Alaska's turn in 2012.

"I reached out to D'Amore because my group had a lot of experience with Alaska's boreal and tundra ecosystems but limited experience with southeast Alaska," McGuire says.

D'Amore welcomed the invitation to help with the carbon cycle assessment. "When you look at where the carbon is on the federal lands, it's mostly held by the Forest Service," he explains. As it turns out, not only was D'Amore's carbon sequestration work on young-growth forests relevant, but his earlier watershed carbon budget research was incorporated into the assessment.

To model the present and future carbon cycle for Alaska, McGuire and the team used datasets containing data on landscape characteristics that would affect carbon sequestration, such as soil texture, fire disturbance, historical climate, and future forest management. "We tried to pull together as much information as we could to create a baseline picture from 1960 through 2010," he explains.

A major finding of the assessment was that during the baseline historical period, the state was nearly carbon neutral because the release of carbon in the boreal forest region of Alaska due to wildfires was offset by the rest of the state sequestering carbon. However, it was estimated that from 2010 to 2099 the state would sequester carbon at the rate of 22.5 to 70.0 teragrams (Tg) of carbon per year. Although wildfires and the subsequent release of carbon into the atmosphere is expected to increase, the volume of vegetative biomass and longer growing seasons is estimated to result in higher volumes of carbon being sequestered. In particular, the study estimates that the forested ecosystems of coastal Alaska will sequester 3.4 to 7.8 Tg of carbon per year.

However, McGuire says that while Alaska is projected to be a sink for the remaining decades of this century, "we expect this pattern to reverse itself and lose carbon based on other modeling studies we've conducted. Because of warming, we shouldn't count on Alaska being a long-term carbon sink; it will likely turn into a [carbon] source." After 2100, permafrost thaw will likely release a substantial volume of carbon into the atmosphere, which may more than offset the carbon being sequestered by Alaska's other ecosystems through photosynthesis.

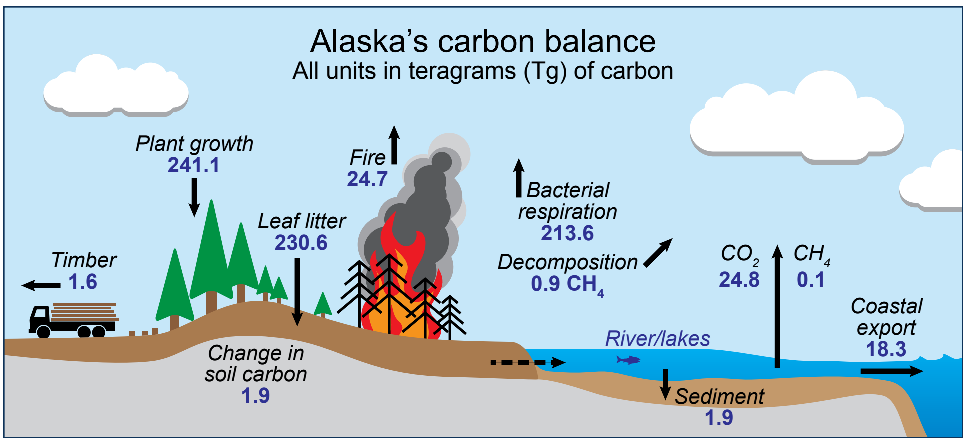
"The big take-home message of this assessment is that some level of mitigation and controlling the rise of atmospheric carbon dioxide in the atmosphere would decrease the potential for Alaska's ecosystems to become carbon sources," McGuire says.

What's Next in Carbon Cycle Research

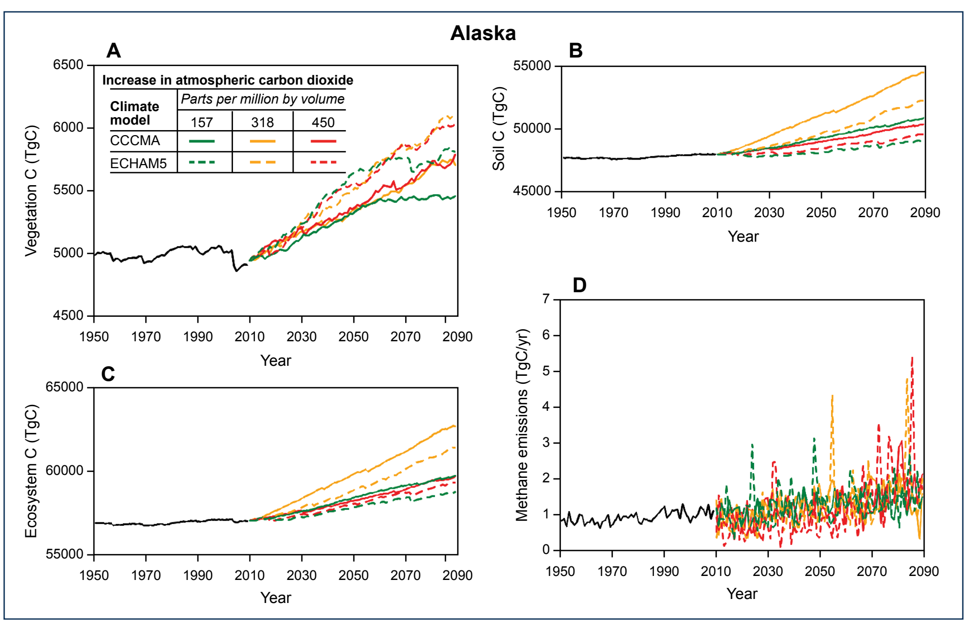
Producing the comprehensive carbon assessment, *Baseline and projected future carbon storage and greenhouse-gas fluxes in ecosystems of Alaska*, was significant. However, both D'Amore and McGuire say the report does not definitively quantify the volume of carbon expected to be sequestered by Alaska's ecosystems in the future; instead, it is important for reducing uncertainties that can help inform land managers.

"We've certainly said it's not the final word on projections in carbon cycling," explains McGuire, "but that it's a benchmark for future assessments to have in terms of moving forward and trying to do better assessments in the future."

"That's what I view these days as my carbon cycle science job," D'Amore adds, "to reduce the uncertainty in the terrestrial carbon sink



Estimated carbon balance of Alaska in teragrams of carbon (10^{12} C) per year from 1950 to 2009 for terrestrial (upland and wetland) and inland aquatic ecosystem components. Adapted from McGuire et al. (2018).



Time series of statewide carbon dynamics for Alaska for the historical (1950–2009) and projected (2010–2099) for (a) vegetation carbon, (b) soil carbon, (c) total ecosystem carbon, and (d) net methane emissions to the atmosphere. These projections were developed using the Canadian Coupled Global Climate Model and European Centre Hamburg Model; the models were run under different emission scenarios. Adapted from McGuire et al. (2018).

because it plays a big role in any greenhouse-gas mitigation strategy."

The tension that D'Amore described earlier between conducting basic and applied research may also be abating when it comes to carbon cycle research. The 2012 Forest Service Planning Rule requires updated forest management plans to include a section on the effects of climate change; basic research is now becoming applied science.

Greg Hayward is a wildlife ecologist with the Forest Service who worked on climate change vulnerability assessments that were incorporated into the forest management plans for the Chugach and Tongass National Forests. He describes his role as helping staff craft the climate plan components, as well as evaluating the potential effects of climate change.

"These assessments looked at the potential consequences, both positive and negative, of a changing climate on the array of resources that the Forest Service pays attention to," he explains, "but also the social, economic, and cultural consequences of those changes in the ecology of the system and changes in resource delivery."

Writing these assessments brought together more than 30 collaborators, one of which was D'Amore. Coincidentally, as the Chugach forest management plan was being updated, the Alaska Land Carbon Project was underway.

"Because of the relationship we have with the researchers, we often benefited from discussions with the scientists regarding preliminary data analysis and results," Hayward says. "The incorporation of science into our work not only includes looking at published research but having access to the scientists for discussions."

The Chugach forest management plan, which was finalized in August 2019, incorporates the latest carbon cycle science. Similarly, as the Tongass National Forest works through the National Environmental Policy Act process to implement its forest management plan, D'Amore's research on the implications of thinning second-growth forests and carbon sequestration will be used in the climate change analysis.

If a tree dies,
plant another in its place.

—Linnaeus [Carl von Linné],
Swedish botanist

Writer's Profile

Andrea Watts is a freelance science writer who specializes in covering natural resources topics. Her portfolio is available at https//:www.wattswritings.wordpress.com and she can be reached at andwatts@live.com.

LAND MANAGEMENT IMPLICATIONS

- Knowing the magnitude of the carbon loss in managed forest stands can help decision-makers evaluate carbon sequestration goals in relation to other goals, such as enhancing wildlife habitat or timber management.
- Information about carbon cycling is necessary for land management plans, which the U.S. Forest Service's 2012 Planning Rule requires to include carbon assessments. In Alaska, both the Chugach and Tongass National Forests have adopted a climate strategy.
- Information about forest carbon sequestration rates informs state and international goals for reducing greenhouse-gas emissions.

Dave D'Amore

Soil scientists collect soil samples from a hillslope dominated by large, mature conifers in southeast Alaska.

For Further Reading

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