US forests face an unclear future with climate change

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A stressed forest in Colorado. Credit: William Anderegg

When you walk through a forest, you are surrounded by carbon. Every branch and every leaf, every inch of trunk and every tendril of unseen root contains carbon pulled from the atmosphere through photosynthesis.

And as long as it stays stored away inside that forest, it's not contributing to the rising concentrations of carbon dioxide that cause climate change. So it's only natural that we might want to use forests' carbon-storage superpower as a potential climate solution in addition to reducing human greenhouse gas emissions.

But climate change itself might compromise how permanently forests are able to store carbon and keep it out of the air, according to a new study led by University of Utah researchers. A study of how different regions and tree species will respond to climate change finds a wide range of estimates of how much carbon forests in different regions might gain or lose as the climate warms. Importantly, the researchers found, the regions most at risk to lose forest carbon through fire, climate stress or insect damage are those regions where many forest carbon offset projects have been set up.

"This tells us there's a really urgent need to update these carbon offsets protocols and policies with the best available science of climate risks to U.S. forests," said William Anderegg, study senior author and director of the U's Wilkes Center for Climate Science and Policy.

The study is published in Nature Geoscience. Find an interactive tool showing carbon storage potential in forests in the U.S. here.

A multi-perspective modeling approach

For this study, the researchers were interested in forecasting changes in the amount of aboveground carbon storage in forests of different regions in the United States. Aboveground carbon refers to any living parts of a tree that are above ground, including wood and leaves or needles.

Scientists can look at the future of forests under climate change in a few different ways. They can look at historical and future projections of climate, or look at datasets from long-term forest plots. They can also use machine learning to identify which climate niches tree species most prefer. Or they can use complex models that include interactions between the ecosystem and the atmosphere.

Anderegg and colleagues, including first author and postdoctoral scholar Chao Wu, chose all of the above.

"Each different method has inherent advantages and limitations," Wu said. "No model is perfect."

"By bringing in many different approaches and different model types and comparing them," Anderegg said, "we can get a sense of what the different models are telling us and how can we learn to improve the models. And we might have much more confidence if all of the models and all of the approaches tell us the same story in a given region."

Analyzing the combined model outputs, the researchers found that although the models' forecasts differed in some ways, they did show some consistency in predictions of how different regions' carbon storage might change in the future. The Great Lakes and Northeastern US, for example, as well as parts of the Southeastern US and the northern Rockies, consistently showed carbon gains in future projections.

But the models also showed significant risks of losing carbon from forests through the climate triple threat of fire, climate stress and insect damage. With those risks, the models projected a net carbon gain in forests nationwide of between 3 and 5 petagrams of carbon by the end of the 21st century (a petagram is a quadrillion grams—about 25 times the mass of all humans on Earth). Without those climate stresses, forests might be able to pack away a net 9.4 petagrams of carbon.

The researchers also applied their analysis to 139 current projects to offset carbon emissions to the atmosphere by aiming to increase the carbon stored in forests through various approaches.

"For carbon offsets to be effective," Anderegg said, "they have to store carbon for a pretty long amount of time—multiple decades to centuries. So if fire's burning them down or insects are wiping out different areas, it could vastly undermine their effectiveness as climate change solutions."

Depending on the model method and the climate scenario, the researchers found that large numbers of carbon offset forest projects, particularly in the Southeastern US and on the West Coast, are projected to lose carbon by the end of the century.

What we still need to know

The results, Wu said, highlight that different climate and ecological models have different strengths and weaknesses, and considering them together reveals the areas of research needed to improve climate projections.

Tree demographic models, for example, include simulations of forest dynamics as old trees die and new trees grow. "But these current models didn't consider the disturbance-vegetation feedback," Wu said, referring to the different types of vegetation besides trees that appear following a disturbance like a forest fire and how they might influence the odds of another disturbance. "And also they didn't consider CO_2 fertilization," or the potential for rising carbon dioxide levels to actually improve plant growth.

Anderegg identified three research questions that could help:

- How much rising CO_2 concentrations might benefit plants and

trees and help them grow more.
- Better data and understanding of climate-driven tree mortality from fire, climate stress, and insects.
- How biomes will shift around. Following a disturbance, for example, some forests may be able to grow back but some may transition to grasslands and be lost entirely.

"These are some of the biggest unknowns that the field is really racing to tackle," he said.

In the meantime, while science works to understand how climate change affects forests, society can help by slowing the pace of climate change.

"Working to tackle climate change as quickly as possible and move to a lower carbon future massively decreases the risks that forests are likely to face in the 21st century," Anderegg said, "and increases the potential benefits that we might get from forests."

More information: Chao Wu, Uncertainty in US forest carbon storage potential due to climate risks, *Nature Geoscience* (2023). DOI: 10.1038/s41561-023-01166-7.
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