Tropical forest carbon absorption may hinge on an odd couple

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Nearly 50 percent of the world's tropical forests are secondary forests that have regrown after clearing, agriculture or cattle grazing. The Agua Salud Project in the Panama Canal Watershed makes it possible for Smithsonian scientists to quantify carbon storage, runoff and biodiversity for land uses including teak and native tree species plantations. Credit: Christian Ziegler

A unique housing arrangement between a specific group of tree species and a carbo-loading bacteria may determine how well tropical forests can absorb carbon dioxide from the atmosphere, according to a Princeton University-based study. The findings suggest that the role of tropical forests in offsetting the atmospheric buildup of carbon from fossil fuels depends on tree diversity, particularly in forests recovering from exploitation.

Tropical forests thrive on natural nitrogen fertilizer pumped into the soil by trees in the legume family, a diverse group that includes beans and peas, the researchers report in the journal *Nature*. The researchers studied second-growth forests in Panama that had been used for agriculture five to 300 years ago. The presence of legume trees ensured rapid forest growth in the first 12 years of recovery and thus a substantial carbon "sink," or carbon-storage capacity. Tracts of land that were pasture only 12 years before had already accumulated as much as 40 percent of the carbon found in fully mature forests. Legumes contributed more than half of the nitrogen needed to make that happen, the researchers reported.

These fledgling woodlands had the capacity to store 50 metric tons of carbon per hectare (2.47 acres), which equates to roughly 185 tons of carbon dioxide, or the exhaust of some 21,285 gallons of gasoline. That much fuel would take the average car in the United States more than half a million miles. Though the legumes' nitrogen fertilizer output waned in later years, the species nonetheless took up carbon at rates that were up to nine times faster than non-legume trees.

The legumes' secret is a process known as nitrogen fixation, carried out in concert with infectious bacteria known as rhizobia, which dwell in little pods inside the tree's roots known as root nodules. As a nutrient, nitrogen is essential for plant growth, but tropical soil is short on nitrogen and surprisingly non-nutritious for trees. Legumes use secretions to invite rhizobia living in the soil to infect their roots, and the bacteria signal back to initiate nodule growth. The rhizobia move into the root cells of the host plant and—in exchange for carbohydrates the tree produces by photosynthesis—convert nitrogen in the air into the fertilizer form that plants need. Excess nitrogen from the legume eventually creates a nitrogen cycle that benefits neighboring trees.

By nurturing bigger, healthier trees that take up more carbon, legumes have a newly realized importance when it comes to influencing atmospheric carbon dioxide, said second author Lars Hedin, a Princeton professor of ecology and evolutionary biology and the Princeton Environmental Institute. Scientists have recently put numbers on how much carbon forests as a whole absorb, with a recent paper suggesting that the world's forests took up 2.4 quadrillion tons of carbon from 1990 to 2007.

"Tropical forests are a huge carbon sink. If trees could just grow and store carbon, you could have a rapid sink, but if they don't have enough nitrogen they don't take up carbon," said Hedin, adding that nitrogen-fixing trees are uncommon in temperate forests such as those in most of North America and Europe.

"Legumes are a group of plants that perform a valuable function, but no one knew how much they help with the carbon sink," Hedin said. "This work shows that they may be critical for the carbon sink, and that the level of biodiversity in a tropical forest may determine the size of the carbon sink."

First author Sarah Batterman, a postdoctoral research associate in Hedin's research group, said legumes, or nitrogen fixers, are especially important for forests recovering from agricultural use, logging, fire or other human activities. The researchers studied 16 forest plots that were formerly pasture and are maintained by the Smithsonian Tropical Research Institute (STRI).

Forest degradation, however, comes with a loss of biodiversity that can affect nitrogen fixers, too, even though legumes are not specifically coveted or threatened, Batterman said. If the numbers and diversity of nitrogen fixers plummet then the health of the surrounding forest would likely be affected for a very long time.

"This study is showing that there is an important place for nitrogen fixation in these disturbed areas," Batterman said. "Nitrogen fixers are a component of biodiversity and they're really important for the function of these forests, but we do not know enough about how this valuable group of trees influences forests. While some species may thrive on disturbance, others are in older forests where they may be sensitive to human activities."

The researchers found that the nine legume species they studied did not contribute nitrogen to surrounding trees at the same time. Certain species were more active in the youngest forests, others in middle-aged forests, and still other species went into action mainly in 300-year-old tracts, though not nearly to the same extent as legumes in younger plots. The researchers found that individual trees reduced their fixation as nitrogen accumulated in soils, with the number of legumes actively fixing nitrogen dropping from 71 to 23 percent between 12- and 80-year-old forests.

"In that way, the diversity of species that are present in the forest is really critical because it ensures that there can be fixation at all different time periods of forest recovery whenever it's necessary," Batterman said. "If you were to lose one of those species and it turned out to be essential for a specific time period, fixation might drop dramatically."

Such details can improve what scientists know about future climate change, Batterman said. Computer models that calculate the global balance of atmospheric carbon dioxide also must factor in sinks that offset carbon, such as tropical forests. And if forests take up carbon differently depending on the abundance and diversity of legumes, models should reflect that variation, she said. Batterman is currently working with Princeton Assistant Professor of Geosciences David Medvigy on a method for considering nitrogen fixation in models.

"This finding is really important because other researchers can now go and put this role of nitrogen fixation into their models and improve predictions about the carbon sink," Batterman said.

Batterman and Hedin worked with Michiel van Breugel, an STRI postdoctoral fellow; Johannes Ransijn, a University of Copenhagen doctoral student in geosciences and natural-resource management; Dylan Craven, a Yale University doctoral candidate in forestry and environmental studies; and Jefferson Hall, an STRI staff scientist and leader of the institute's Agua Salud Project that maintains and studies the plots the researchers examined.

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