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CO₂: Don't count on the trees

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FORTY-FIVE minutes' drive from Panama City, followed by a 20-minute boat ride and a 30-minute trek into the rainforest, will bring you to some of the best-studied trees in the world. On a half-square-kilometre plot of land on Barro Colorado Island, the lives and deaths of precisely 208,387 trees have been tracked for 20 years, like patients in a clinical trial. In that time the trees have been monitored for signs of how tropical forests are responding to climate change. Now the news is in, and it isn't good.

It has long been assumed that forests will be the "get out of jail free card" we need to help soak up spiralling carbon dioxide emissions. Much of that hope has been pinned on tropical forests, the so-called "lungs of the planet", with some studies suggesting that elevated CO₂ levels are allowing rainforests to grow more quickly, locking away the extra carbon in wood or soil mulch. Now measurements from the Smithsonian Tropical Research Institute (STRI) on Barro Colorado Island, and from other sites around the world are starting to suggest quite the opposite. Trees in these areas are starting to grow more slowly - a sign that they may already be suffering from climate change and might not be able to lock away our CO₂ after all. "It is potentially very worrying," says climatologist Rachel Warren from the University of East Anglia in the UK.

The idea that trees will help soak up our carbon emissions has been building for decades. In the early 1960s, when it was first noted that atmospheric CO₂ levels were rising, researchers speculated that the world's plants would respond by taking more carbon from the air. Laboratory experiments seemed to support that idea: plants grown in chambers pumped with extra CO₂ grew up to 40 per cent faster than normal. The idea got another boost in 1995, when John Grace, an

atmospheric scientist at the University of Edinburgh, UK, reported that the Amazon forest was sucking up some of the CO₂ that human activities produce. Grace monitored CO₂ concentrations over a square kilometre of the Amazon over two years, and found that the air seemed to lose CO₂ as it flowed over the forest. He calculated that each square kilometre was inhaling about 100 tonnes of carbon per year, a huge amount when you consider that the Amazon covers 6 million square kilometres.

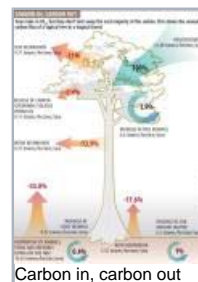
Not everyone bought into this idea, though. "I heard about John Grace on the radio, and I didn't believe a word of it," says Oliver Phillips, an ecologist at the University of Leeds, UK. At the time Phillips was studying rates of tree growth in the Amazon, and he knew that measuring the amount of carbon that trees inhale doesn't equate to the amount stored. Forests absorb large amounts of carbon as trees grow, but they also release it back into the atmosphere as they respire to produce energy, and as they die and decay. The important number is the difference between those two rates. A forest that is gaining carbon over time is usually storing away only a small percentage of the total carbon absorbed through photosynthesis (see Diagram).

To test Grace's idea, Phillips looked at historical tree growth records from several small plots in the Amazon over the previous 20 years to see if their mass was increasing over time as Grace had predicted. Since it's impossible to weigh a tree without ripping it from the ground, he used what are known as allometric equations, which foresters use to convert a tree's trunk diameter into an estimate of its mass. He found that the total tree mass was indeed increasing (*Science*, vol 282, p 439). Averaged over 50 plots, he calculated that the forest was adding 71 tonnes of carbon per square kilometre per year, which is close to what Grace had found. "I was very surprised," Phillips says.

Growing slow

He then extended his analysis to the entire RAINFOR Network, an international research collaboration that covers more than 100 plots in the Amazon. Based on his results, the Amazon should be absorbing over 600 million tonnes of carbon per year. Extrapolate this result to all of the world's tropical forests, and it suggests that they absorb some 15 per cent of the carbon that humans are emitting. Climate modellers take this sort of number into account when they make predictions of how quickly the atmospheric CO₂ levels will rise, and how quickly temperature will rise as a result. It buys us time to figure out how to reduce our CO₂ emissions.

So far, so good. But a study published earlier this year suggests that this convenient tropical carbon sink may not last much longer.



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In the study, Ken Feeley, a tropical ecologist now at Wake Forest University in Salem, North Carolina, looked at growth trends for a total of 500,000 trees in two plots - one on Barro Colorado Island, the other in Pasoh, Malaysia. Instead of using allometric equations to calculate tree biomass, Feeley compared the trunk diameters of each tree from one survey to the next to derive five-year growth rates. The results were a big surprise.

In Barro Colorado, tree growth as measured by trunk diameter has slowed by 25 per cent over the past 20 years. Tree growth in Malaysia declined by the same amount in the past 10 years. Growth was reduced even more in saplings, by a whopping 35 per cent (*Ecology Letters*, vol 10, p 461). "I was shocked," says Feeley. "We had this incredibly strong and consistent pattern at both sites."

Does that mean that either Phillips's or Feeley's study somehow got it wrong? Not according to Feeley. "I believe both are correct," he says. "The only conclusion we can draw is that different parts of the tropics are acting differently." This could suggest, among other things, that climate change is already eroding the tropics' ability to store carbon.

Feeley admits that the slower growth in his plots could result from a number of factors, including warmer weather, lower rainfall, or increasingly frequent cloudy days. But a similar study, conducted by husband-and-wife team Deborah and David Clark at La Selva Biological Reserve in Costa Rica, provides some clues. The Clarks have measured the growth of a set of 166 trees in La Selva every year since 1984. They found that although the rate of growth changed from year to year, between 1984 and 2000 growth was significantly slower in hot years. There was an especially strong correlation with minimum night-time temperature: the warmer the nights, the slower the growth.

This could help explain Feeley's results, as a tree's growth and carbon sequestration rate is determined not only by the amount of carbon it locks into sugars through photosynthesis, but also by the amount of sugar that it burns back into CO₂, which is released into the air. The Clarks suspect that increased temperatures might accelerate the trees' metabolic rate at night and cause them to burn off more of the sugars that they work so hard to photosynthesise during the day. To a couch potato looking to lose a few pounds this would be a dream come true, the equivalent of sleeping away your double cheeseburger. But for a tropical forest that we're counting on to sequester carbon from our tailpipes, it is bad news.

Temperature limit

The Clarks tracked the growth of just 166 trees, but other observations show echoes of the pattern they saw for the entire tropics. Stephen Piper and the late Charles Keeling, both of the Scripps Institution of Oceanography in La Jolla, California, compiled data from a global network of atmospheric monitoring stations to estimate the amount of CO₂ flowing into or out of the world's tropical landmasses from 1984 to 2000. When Piper and Keeling compared a year-by-year plot of their results with a plot of tree growth measured by the Clarks, the peaks and troughs matched almost exactly. "It is remarkable that the correlation looks so good," says Piper.

Faster plant respiration during the night is not the only challenge to tree growth. High temperatures may also slow photosynthesis so plants can't take in as much carbon in the first place. According to a study by Edgard Tribuzy of the Federal University of Amazonas in Humaitá, Brazil, and Jeffrey Chambers at Tulane University in New Orleans, Louisiana, tropical trees may already be near their temperature limit. For two years Tribuzy monitored the temperature and rates of photosynthesis in the Brazilian rainforest canopy. He found that photosynthesis slowed as leaf temperature rose above 33 °C. When the mercury topped 36 °C, photosynthesis hit the wall: the leaves closed down their CO₂-inhaling pores, called stomata, to avoid dehydration. Leaves high in the forest canopy - those that absorb most of a tree's CO₂ - often rose above this threshold early in the afternoon.

It's uncertain whether this photosynthetic shutdown is already limiting tree growth, since even trees at ideal temperatures don't photosynthesise for the entire day. But if temperatures continue to rise, at some point it will, Chambers says.

Taken together, the findings of Tribuzy and Chambers, Feeley and the Clarks paint a troubling picture. It has long been known that warmer temperatures will eventually catch up with forests, blunting their growth, killing trees and flushing CO₂ back into the atmosphere, but no one imagined it had already begun. "We thought this wouldn't happen until global temperature increased by 2 °C," says Warren. "It would be terribly worrying if that feedback is already kicking in."

We can't yet be certain that this is what's happening. Critics argue that the history of the forest plots studied could have skewed the results. A patch of tropical forest that is disturbed by an event such as a hurricane, fire or logging will continue to change for another 200 years, as one group of tree species gradually replaces another. It is known, for example, that the amount of carbon a forest absorbs increases as smaller trees give way to larger ones. If Phillips happens to have chosen plots that were disturbed 100 years ago, the increasing tree biomass he saw might reflect this process rather than the effects of climate change, though Phillips argues that since his investigation covered many small plots, such local effects should have evened each other out.

Likewise, if Feeley's plots were located in areas with large numbers of old trees, then slower growth might reflect aged trees nodding off into senescence, and not be an apocalyptic sign of climate change. Another difficulty is that although the trees in Malaysia and Barro Colorado were followed for 10 and 20 years respectively, the trees were only measured every five years, making it difficult to relate the slower growth to changes in temperature or rain. "That's too short a sequence to show correlation between some annual climate factor and what the forest is doing," says Deborah Clark.

Feeley is working to eliminate some of these uncertainties by using Phillips's methods to calculate changes in biomass at Barro Colorado, Pasoh and elsewhere, and correcting for natural processes of forest maturation unrelated to climate. His preliminary results suggest that some plots are losing biomass, some gaining it and some staying about the same. These results highlight the fact that slower growth doesn't necessarily mean a forest is losing biomass: that depends not only on the growth rate of trees but also the death rate, which could independently be rising, falling or staying the same. Overall, Feeley's results could mean that decreases in growth haven't yet eroded away the ability of forests to sequester carbon - although all of them could change from carbon sinks to net emitters of carbon in the

future if growth continues to slow.

This debate overlooks another change that's already creeping into tropical forests. Never mind the heat, the rising CO₂ is itself changing the delicate ecology of the Amazon, giving some species a leg-up over others. This could have a profound impact on the Amazon's ability to store carbon.

Following Phillips's 1994 finding that, in the Amazon at least, higher CO₂ was driving trees to grow, reproduce and die more quickly, William Laurance at the STRI observed that this faster turnover is actually changing the Amazon's mix of trees, giving faster-growing species an edge. Across 18 forest plots, the dominance of quickly growing tree species increased over 20 years, while the dominance of slow-growing species decreased.

On the face of it, this sounds like a good thing. However, fast-growing trees produce wood that is up to 60 per cent less dense than in some slow growers. So a major shift from slowly to quickly growing trees across the Amazon could drastically reduce the carbon stored in wood. This would more than outweigh the 0.4 per cent annual increase in carbon storage that Phillips sees in his studies. "If you had a big shift in tree composition over a few decades, that alone would be enough to wipe out the carbon sink," Phillips warns.

It doesn't stop there. In just 20 years, both Phillips and Joseph Wright of the STRI have documented increases of between 50 and 100 per cent in lianas, woody vines that spiral up the trunks of established trees to reach sunlight. Lianas strangle trees, causing them to die and fall, particularly large trees - the kind that store carbon so well. This has tropical researchers worried. "Definitely they're going to reduce tree growth," says Wright, "and thereby reduce the carbon in the trees."

What's more, Wright has found evidence that higher levels of CO₂ in the atmosphere might not necessarily translate into more carbon stored in wood. "If a tree has extra carbon, why is it going to grow extra wood?" he says. Trees might invest extra carbon in leaves or flowers, which soon end up rotting on the forest floor, returning their carbon to the atmosphere. Wright recently found that the production of flowers by plants on Barro Colorado has increased dramatically in the past 18 years - by 20 per cent for trees and 70 per cent for lianas. No one has yet demonstrated that lianas, or changes in wood density or flowering, are reducing carbon storage, but it remains a possibility.

Sadly, trees are no longer looking like such a safe bet for mopping up our emissions. None of this is to say that we should not preserve tropical forests, of course, or not replant them where they've been cut down. A forest still stores more carbon than a grassland, pineapple field or parking lot, but we should not expect those trees to perform miracles.

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Smithsonian Tropical Research Institute, Barro Colorado
http://www.stri.org/english/research/facilities/terrestrial/barro_colorado/index.php

The Amazon Forest Inventory Network (RAINFOR)
<http://www.geog.leeds.ac.uk/projects/rainfor/>

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