https://doi.org/10.1038/d41586-026-02291-0

News & views

Forest ecology

No rule of thumb explains tropical-forest carbon

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Ecologists have long wondered why some tropical forests store more carbon than others. A global satellite survey offers an explanation.

Tropical forests are some of Earth's largest carbon reservoirs, yet they differ enormously in how much biomass they produce, and therefore in how much carbon they store[1]. Understanding this variation is important to predict how these ecosystems might respond to climate change, and whether they will keep slowing the accumulation of carbon dioxide in the atmosphere. But despite decades of research, ecologists still disagree about which climate factors matter most for tropical forests. Writing in *Nature*, Nunes *et al.*[2] show that climate effects on tropical-forest biomass differ from one region to another. And even within regions, the main driver changes depending on local conditions. The findings suggest that ecologists' disagreements have arisen because these researchers have been looking for the wrong thing: a single rule that explains how climate affects biomass in tropical forests.

Difficulties might arise in this type of study in part because tropical forests are anything but uniform. Forests in the three main tropical regions – the Amazon, the Congo Basin and southeast Asia – have different evolutionary histories, species compositions, soil types, topographies and disturbance regimes (the patterns of abrupt disruptive events, such as storms, floods and fires, that shape environments). Long-term studies of specific plots of land have transformed scientists' understanding of tropical-forest ecosystems[3], revealing how environmental variation influences tree growth, mortality and carbon storage. But such plots cover only a tiny sliver of global tropical biomes, and they are often biased because they tend to be set up at locations that field teams can reach. Studies built on data from these patchworks of plots can end up comparing forest regions that differ by much more than just their climate.

Nunes and colleagues sidestep this problem by using an enormous data set that includes around 16 million estimates of aboveground biomass from NASA's Global Ecosystem Dynamics Investigation instrument. This technology fires laser pulses from the International Space Station to measure forest canopy height and estimate biomass[4]. The data cover intact lowland forests across the three main tropical regions.

The geographical scale of the study enabled the authors to compare forests spanning nearly the full range of climate conditions found in the tropics. And rather than trying to settle which single driver – temperature, drought or disturbance – matters the most in all three regions, they ask a different question: does the importance of each driver change depending on where you are? The answer is an emphatic yes.

The authors find that temperature is most strongly associated with biomass loss in the Amazon and the Congo Basin. In the Congo Basin, each 1 °C increase in mean annual temperature leads to a decline in biomass of around 28 megagrams per hectare – about 2.5 times the decline of the Amazon's biomass. This finding is consistent with previous work showing that tropical forests are sensitive to temperature[5], although the effect observed by Nunes *et al.* is considerably stronger. Southeast Asian forests show almost no direct response to temperature but are much more sensitive to seasonal drought and long-term water limitation than are the other two regions. Some of these variations probably trace back to each region's climate history and the flora that have evolved there.

But the sizes of the effects produced by different climate factors are not fixed even within a particular region. Temperature has a bigger impact in dry areas; the effects of drought strengthen or weaken depending on background aridity; and the impact of storm damage depends on environmental conditions. Climate, in other words, acts through interactions with the broader environmental setting rather than through universal, independent effects.

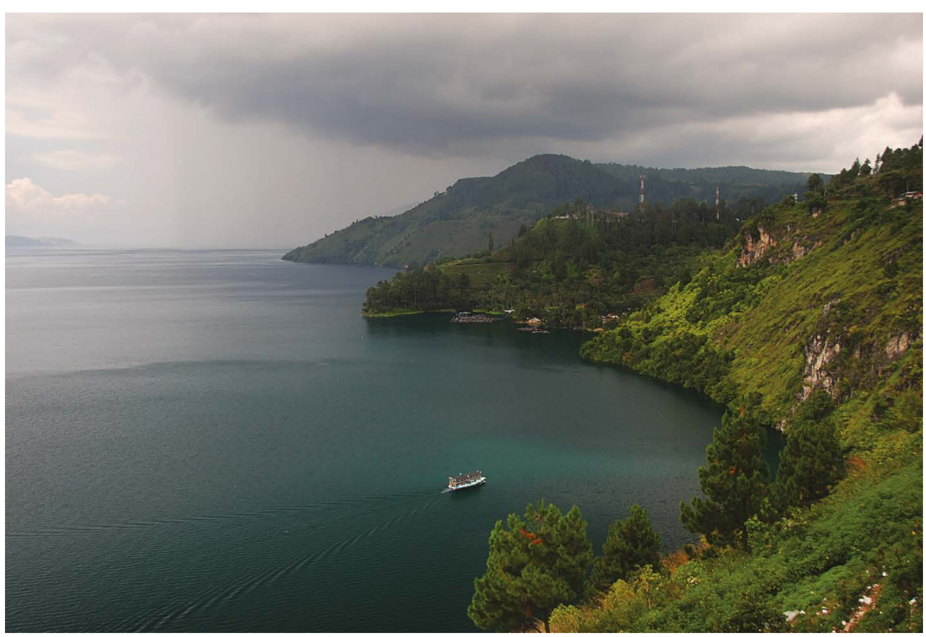

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Figure 1 | A storm approaches Sumatra, Indonesia. Nunes *et al.*[2] report that storm prevalence correlates strongly with lower biomass in the tropical forests with the tallest trees (those greater than 70 metres in height) – in Sumatra, for instance.

The researchers' findings help to explain apparent contradictions in the scientific literature that have led to disagreement between ecologists. Previous studies probably weren't wrong so much as incomplete, each sampling only part of a large, highly variable landscape. A pattern found in one region can be weakened or reversed in another, and even forests only a few hundred kilometres apart can respond differently depending on local conditions. Across the tropics, there might not be one climate–biomass relationship, but many, layered by geography and the local environment.

One of the most striking findings in Nunes and colleagues' study concerns storms. In the tallest tropical forests (with trees more than 70 metres in height, such as those in Sumatra in western Indonesia; Fig. 1), storm prevalence correlates strongly with lower biomass, consistent with previous findings[6]. The stature of towering forests, such as the stands of trees in the Dipterocarpaceae family in southeast Asia, is usually credited to evolutionary history and species composition[7,8]. But the findings of Nunes and colleagues suggest that regional disturbance regimes deserve some of that credit, too: they shape not just which trees grow tall but also how much carbon the forest stores.

The study's implications go beyond tropical ecology. Earth-system models, which are used to project future climate trends, capture some of the regional differences in soil type, topography, species composition and other environmental factors, but establishing the net effect of these interactions remains a challenge. The rich, near-continental data set assembled by Nunes and colleagues could offer a valuable benchmark for testing how well such models reproduce real-world variation in climate sensitivity across the tropics, and for refining them when they fall short. This will be important for predicting how carbon–climate feedback loops play out as droughts and heat extremes intensify owing to climate change[9].

These regional differences also have practical consequences. If the Congo Basin's carbon stocks are unusually sensitive to warming and southeast Asian forests are disproportionately vulnerable to even mild water limitation, then a uniform forest-management policy could misjudge climate risks at local and regional scales. Climate projections and conservation planning could benefit from treating tropical forests as several distinct carbon reservoirs. Knowing which climate vulnerabilities are relevant to which region could help with targeting restoration and adaptation efforts towards the forests that are most at risk of degradation.

A few caveats are worth keeping in mind. The analysis presents large-scale statistical associations rather than proven mechanisms, and a good deal of the observed variation in biomass is still unexplained. Some of that is probably due to differences in species composition, disturbance history and ecological processes playing out at spatial and temporal scales too fine for a continental data set to pick up. Connecting broad patterns to the finer mechanics of tree growth, death and the recruitment of new trees would be a good next step.

The paper's real contribution might be less about the data that it presents and more about the question that it asks. Instead of hunting for the one or two climate variables that govern tropical-forest biomass, Nunes *et al.* ask why various tropical forests respond to distinct climate drivers, and under what conditions those drivers matter most. Rather than searching for one climate rule that applies everywhere, they built biogeographical differences and environmental context directly into the framework that they used. The result is a messier picture than a single rule would provide, but probably a truer one.

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The authors declare no competing interests.