FOREST FACTS
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Drought in the Amazon
– what can a largescale field experiment tell us about model predictions?

FIGURE 1. View across the Caxiuaná forest. The position of the field site is indicated with a red star (figure inset). Photo: Antonio Carlos Lola da Costa.

- The Amazon rainforest stores up to 120 billion tonnes of carbon (C) in vegetation, but the stability of this stored C is potentially threatened as global climate change brings more frequent and severe drought events to the region.

- To better predict Amazon drought responses, a large-scale drought experiment was installed in eastern Amazonia in 2000. Plastic panels were placed around two meters above the ground across a 100 × 100 meter area, reducing rainfall by 50 %. A wide variety of plant responses were then recorded over the following years.

- The forest proved to be remarkably resilient, showing little clear change in mortality to the first few years of drought. By the third year, however, trees began to die with the largest individuals the worst affected. Tree mortality may have been caused by the process of "C starvation", whereby the C required to sustain vital metabolic processes could not be supplied by photosynthesis.

- This research provides key evidence for the likely patterns and mechanisms of forest responses to drought across a globally important ecosystem facing dramatic climatic shifts over this century.

FIGURE 2. The large-scale drought experiment in Caxiuaná, north-eastern Brazil from above (left) and below (right). Rainwater is intercepted by plastic panels (seen from above to the left, and from below to the right) and channeled away from the experimental plot. Photos: Antonio Carlos Lola da Costa.

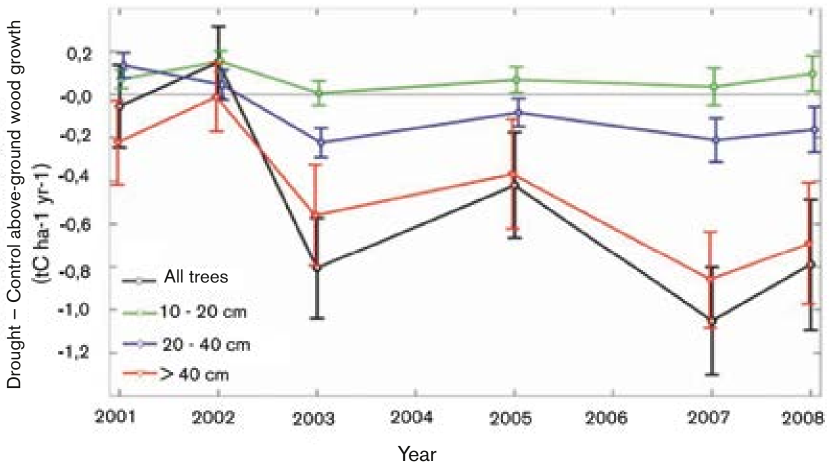
Since the first report of the Intergovernmental Panel on Climate Change in 1990 brought the threat of climate change to the attention of governments and public worldwide, the importance of the Amazon in regulating regional and global climate has come into the spotlight (Figure 1). Research efforts became more urgent with the production of the first global model to include terrestrial processes in simulations of global climate, which showed a large increase in atmospheric carbon dioxide (CO_2) levels, compared to simulations without terrestrial processes. This effect was largely driven by drought-induced death of the Amazon forest, resulting in a massive release of CO_2. If drier conditions in the future do drive a transition in the forest structure from dense, moist forest to more open, seasonally dry woodland, this implies a substantial loss of vegetation C to the atmosphere, but current models differ widely in exactly how much this loss will be and how it will occur. Central to these discrepancies amongst models is the general paucity of field-based experimental data about how real Amazon forests respond to drought.

To remedy this situation, a large-scale drought experiment was installed in 2000 in eastern Amazonian old-growth forest (Figure 2). To divert rain away from a 100 × 100 meter area of forest, a system of plastic panels and drains were constructed at around two meters height above the ground. During rain events, water was channeled from the panels along drains and away from the plot (Figure 2). The treatment achieved a 50 % reduction in rainfall reaching the soil, and halved wet season soil moisture, compared to forest outside the experiment. A wide range of scientific measurements were initiated within the plot to track the different pathways for C within the forest, and the net effect of these different components upon the total CO_2 flux from the forest to the atmosphere. At the same time, identical measurements were conducted in an adjacent, unmodified plot to get a picture of normal forest C cycling in the absence of drought. A wide range of scientific measurements were initiated within the plot to track the different pathways for C within the forest, and the net effect of these different components upon the total CO_2 flux from the forest to the atmosphere (Figure 3).

FIGURE 3. Field work in the Amazon (left), measuring tree diameter (upper right) and root biomass (bottom right). Photos: Antonio Carlos Lola da Costa and Daniel Metcalfe.

Large trees are particularly vulnerable to drought

Given that the drought treatment reduced rainfall by such a large amount it is perhaps surprising that it took several years before any clear increase in tree mortality in the forest was observed. This may reflect an evolved capacity to survive relatively short periods of drought, since such events occur regularly across the Amazon as part of the El Niño – La Niña cycle. However, the precursors to mortality were detectable earlier – as large trees on the droughted plot (over 40 cm stem diameter at breast height) drastically reduced their growth already in the first year of the experiment (Figure 4). By contrast, smaller trees showed no clear change in either growth or mortality rate even after eight years of continuous drought. This data strongly suggests that



FIGUR 4. Difference in tree growth between the droughted and unmodified, control, plot. The black line denotes the sum of all tree size classes; other colored lines represent trees of different diameters (da Costa, A.C.L et al. 2010).

new models, incorporating individual tree responses and interactions with each other, may be very important to accurately capture ecosystem-level forest responses to climate change.

There is not yet any solid mechanistic explanation for the different patterns of mortality observed in this experiment. However, it is likely that larger trees may have a particularly difficult time balancing the competing demands to minimize water loss whilst at the same time capturing enough CO_2 to meet their basic metabolic requirements.

Droughted trees use more carbon than they gain from photosynthesis

From an evolutionary perspective, it makes sense that trees which have evolved in an environment with regular but relatively short droughts should prioritize minimization of water loss over CO_2 capture because the shortfall in C will be relatively short-lived. However, when climate conditions move beyond those naturally encountered over the evolutionary history of the forest, such as those imposed by the drought treatment or perhaps within the next few decades with climate change, these adaptive responses may be critically flawed. The forest is faced with a novel situation – multiple, consecutive years of drought – where there is little or no chance to reverse their C deficit.

The optimal solution to this new, challenging situation may involve fundamental shifts in plant physiology or anatomy which are simply too radical for most plants to achieve. If this is the case, then plants may die from "C starvation", as they run out of the C necessary to maintain metabolism and growth.

To slow this process, the trees droughted in this experiment reduced their growth (Figure 5). But surprisingly, their respiration dramatically increased (Figure 5). It is not clear what function the increased respiration served, but it was sufficient to offset any saving made via lower growth, and to transform the forest as a whole into a large C source (Figure 6). By contrast, on the control plot, the forest as a whole was C neutral, and the trees maintained an approximate balance between photosynthetic C uptake and C use on growth and respiration (Figure 5). These data suggest that future droughts might transform large portions of the Amazon forest from a C sink into source, thereby further increasing atmospheric CO_2 concentrations and hence the rate of global climate change.

Future directions

The experiment described here is one of only a handful worldwide. To meet the understandably intense political and public demand for information about climate change impacts, global climate modelers are forced to use these few observations from a limited number of locations to extrapolate across the earth's surface. In the case of this experiment, novel patterns were observed which are not currently represented in modelled responses to drought. While there are some indications of the likely underlying mechanisms controlling these observed responses, much remains to be done. For example, more experimental work is required to determine the precise mechanisms of drought-induced mortality.

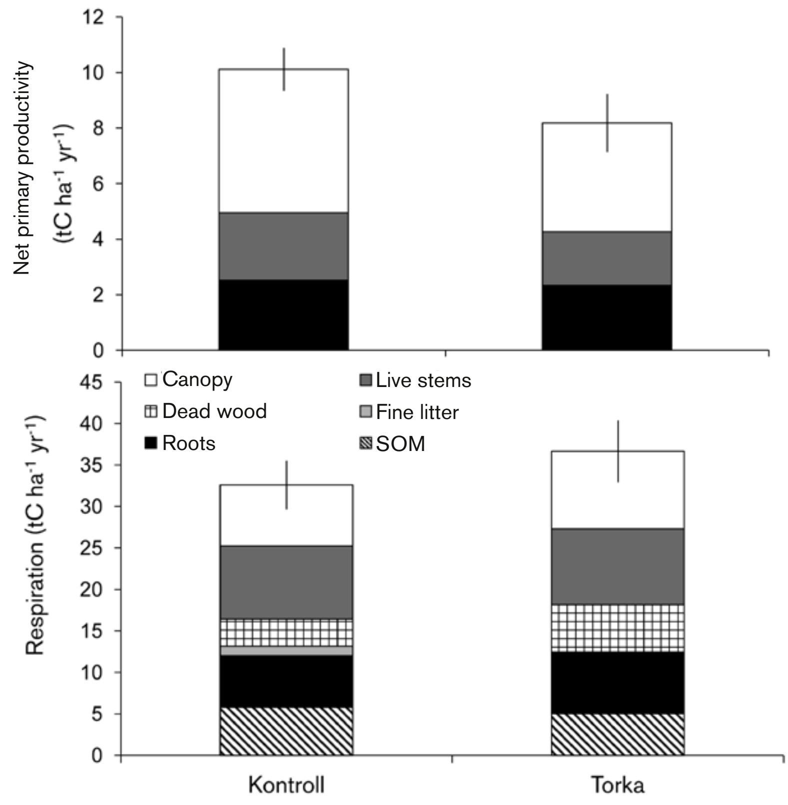


FIGURE 5. Forest growth (top) and respiration (bottom) from different sources on the droughted and unmodified, control, plots. SOM refers to soil organic matter.

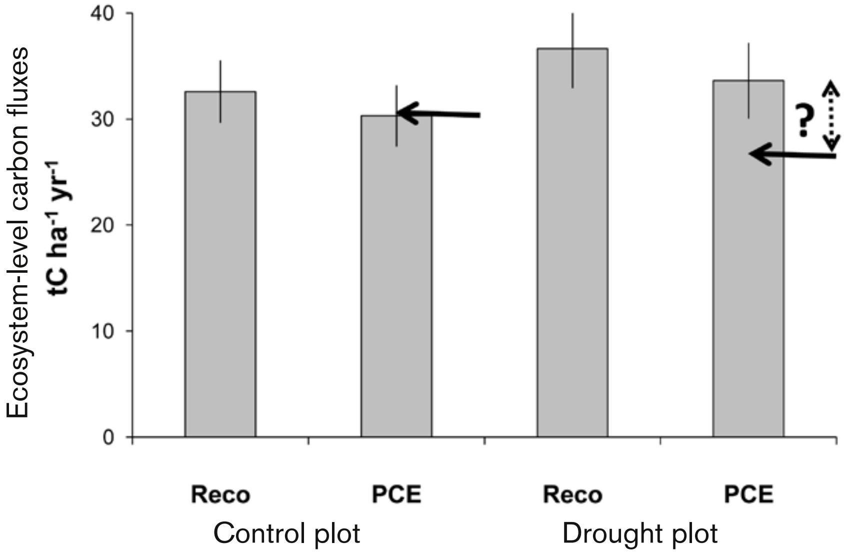


FIGURE 6. Ecosystem-level respiration of carbon dioxide (Reco) and plant carbon expenditure on respiration and growth (PCE) on the drought and unmodified, control plots. The black arrow marks the level of forest carbon intake via photosynthesis (GPP).

Another issue is the accuracy of the overall C expenditure and ecosystem respiration estimates. In the case of this experiment, we had a number of independent checks which indicate that the values are broadly correct. Nevertheless, other approaches such as isotopic labelling of plant tissue and satellite remote sensing could provide novel insights.

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Keywords

Climate change, drought, tropical forest, carbon allocation, tree mortality.

Read more

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