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Drought, tree death and the carbon balance

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Widespread tree deaths during recent unprecedented droughts and heat waves in Australia and overseas suggest that global warming is escalating the collapse of forest ecosystems. So what is happening to the trees? And what does this mean for the planet's future carbon balance?

Credit: Dawson Swan/istockphoto

Drought and other extreme climate events can lead to a decrease in the amount of carbon stored in forests and induce shifts in species distribution and forest types over a given area. However, we are only now starting to understand the processes that kill thirsty trees and what this might mean for long-term patterns in carbon cycling and biodiversity.

Australia is well known for its variable climate and the astonishing capacity of its flora to survive historical drought and disturbance. Despite this, record heat and drought in Tasmania in 2013 and an extreme drought event in south-western Australia in 2010-2011 pushed some plant species over the edge, with significant patches of collapsed canopy and dead trees observed across woodland and forest landscapes.

Whether drought intensity and duration is increasing remains difficult for scientists to predict. But there is good evidence to suggest that temperatures are rising, and that changes in the timing and distribution of rainfall is consistent with projections from global climate models.

Trees tend to be long-lived, with life spans from tens to thousands of years. As a result, most trees face many challenging environmental conditions throughout their lives.

Even the act of lifting water against gravity to the canopy represents a significant challenge, which has only been overcome by the evolution of hydraulic structures that, in some cases, enable trees to reach heights approaching 100 m. Despite this adaptation, water availability is a major constraint on tree productivity.

Credit: P. Mitchell

Trees have many strategies to cope with drought, which include reducing water loss through their leaves. Water loss at the leaf surface is controlled through stomata – the tiny pores on the leaf surface that act as gateways for the exchange of carbon dioxide from the atmosphere into the plant, and for water vapour to exit into the atmosphere.

By converting atmospheric carbon via photosynthesis into carbohydrates, which form the basis of many food webs, stomata are critical regulators of life's delicate balancing act.

However, during the course of a drought, trees will try to avoid dehydration by shutting stomata. In doing so, they significantly restrict photosynthesis, cutting off their source of vital carbohydrates for growth and survival. When a tree cannot meet its internal water or carbohydrate requirements, this results in cell death and, ultimately, the death of the entire organism.

Our research – part of a growing global effort to unravel how tree response affects the capacity of forests to survive future drought – has shown that the way in which a tree balances demands for water and carbon can tell us how it will die.

By manipulating water supply in three common Australian forest species, we tracked key indicators of their capacity to regulate their water and carbohydrate balance. It was previously thought that a tree dies when its hydraulic system collapses – in other words, that trees tend to die of thirst. However, our research shows that not all trees are susceptible to this process: in fact, a tree can also potentially 'starve to death' by depleting its stored sugars.

Credit: P. Mitchell

We have begun to build a picture of the climate conditions associated with tree death across a range of ecosystems, from mulga shrublands to wet sclerophyll forests. What we are finding is that tree death occurs when drought and temperature conditions exceed 98 per cent of the total range of conditions experienced at that particular site. In other words, there is a common critical drought and temperature threshold that results in significant drought damage or death across many different ecosystems.

While many other factors help determine which species or individuals are most vulnerable – for example, tree age, soil type, and pest damage – these new observations provide a baseline against which we can compare future climates, enabling us to develop tools to assess drought risk to forests.

A drought mortality working group within the Australian Centre for Ecological Analysis and Synthesis is currently investigating how to characterise drought from an ecological perspective, not just a purely meteorological one.

Credit: P. Mitchell

For example, a drought that affects farm productivity may have little impact on a neighbouring forest. This highlights the importance of understanding the difference between climate drivers, on the one hand, and the corresponding resistance and resilience of the affected species and ecosystem on the other.

The working group aims to bring together a large body of data on the ecological and physiological sensitivities of forest species to drought and temperature stress, and define plant traits that govern how an ecosystem might respond.

This type of information is critical for modelling feedbacks between climate and vegetation, and defining the long-term impact of climate extremes on carbon storage in terrestrial ecosystems.

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