Unravelling eucalypt responses to heat waves in a warming world

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A team led by Professor Mark Tjoelker has made breakthrough contributions to the field of plant biology and global change science. Using unique outdoor climate-controlled pods to test the response of Australia's native eucalypts to climate change, the team discovered that trees "sweat" to cool themselves during record-breaking heat waves.

Research Summary

Record-breaking heat waves are a signature feature of climate warming. Rising concentrations of greenhouse gases in the atmosphere are expected to drive an increase in the frequency and intensity of heat waves. Indeed, if the heatwaves observed this past January throughout Australia portend a warmer world, climate change has already arrived.

Heat waves pose health risks to humans as well as Australia's plants and animals. However, for native trees, the nature and limits of tolerance to extreme temperature is relatively unknown. Filling this knowledge gap is particularly crucial as trees play an outsized role in providing climate-regulating services of carbon sequestration and evaporative cooling.

Research led by Professor Tjoelker and his team provides new insights into whether Australia's native trees will cope with ever-rising average temperatures and extreme heat waves. The findings, published in the journal *Global Change Biology*, reveal the mechanisms by which Australian eucalypts function under extreme temperatures and have led to a better understanding of how trees cope with heat wave conditions.

Trees, like all green plants, take up carbon dioxide from the air through photosynthesis while losing water back into the air through a process known as transpiration. This occurs because leaves are covered with thousands of tiny pores that open to absorb carbon dioxide and, in turn, evaporate water into the air. These pores, called stomata, will close when conditions become unfavourable for photosynthesis, stopping both photosynthesis and water loss. Thus, hot and dry conditions during heatwaves are expected to cause both photosynthesis and transpiration to cease.

The team, based at the Hawkesbury Institute for the Environment, used unique climate-controlled pods located at Western Sydney University's Hawkesbury campus forest to grow trees local to the Sydney region under current climate and a 3 °C warmer climate of the future and then impose a four-day, high-intensity heat wave.

The outdoor pods are unique as trees can be grown up to 9 meters in height in a fully controlled environment while accurately measuring the trees' rates of photosynthesis and water use. The pods control air temperature and humidity and measure whole-canopy carbon dioxide and water exchange in real time. This enables assessment of heatwave impacts on integrated exchange of carbon dioxide and water of large trees rooted in soil with natural diurnal cycles of sun, temperature and humidity. This avoids limitations inherent in experiments that use small trees in pots and provides an opportunity to monitor the function of larger trees before, during and after a heat wave.

Within the 12 pods, researchers grew individual trees of Parramatta red gum (*Eucalyptus parramattensis*), a species endemic to the Sydney basin. Six trees were grown under current temperatures that tracked ambient climate conditions at the site, while the remaining six trees were grown with an additional 3 °C to simulate climate warming. After 12 months, in which time the trees grew to more than 6 meters in height, researchers withheld irrigation for one month to dry surface soils. The team then imposed a four-day heatwave with daily temperatures peaking at 43 °C to half the trees in each temperature treatment; the remaining trees served as controls. Growing trees at both current temperatures and with 3 °C of warming provided a test of whether warmed trees of the future will be better able to cope with an extreme heat wave.

Parramatta red gum trees growing in climate-controlled pods and exposed to a 4-day heat wave with peak midday temperatures above 43 °C as seen in thermal imagery. Credit: Mark G. Tjoelker Western Sydney University

The results revealed that these native trees showed a remarkable capacity to cope with the heatwave, using a range of different strategies to avoid being damaged by the heat. The key finding was that as air temperatures rose to peak midday temperatures above 43 °C during the heat wave, the trees stopped photosynthesis as expected, but surprisingly, continued to use large quantities of water, sourced from deep in the soil profile.

The evaporation of water from the leaf surfaces through the tiny stomatal pores resulted in cooling of the leaf surfaces. The evaporative cooling helped keep leaf temperatures below critical temperatures that would have resulted in leaf injury and loss. This finding is important as it reveals a new means by which trees, in effect, keep cool during heat waves.

The trees also rapidly increased the high-temperature thermotolerance of leaves. Within 24 hours of the start of the heatwave, the threshold temperature at which leaves start to become heat damaged had increased by a further 2 °C, providing an added thermal safety margin for sun-exposed leaves.

The trees grown in the 3 °C warmer conditions coped equally well as the others, indicating that climate warming will not confer added heat wave tolerance. Although photosynthesis ceased during the midday peak temperatures of the heatwave, the longer-term ability of trees to absorb carbon was not impaired once the heatwave ended.

Under hot and dry conditions, plants normally stop transpiring in order to conserve water. This is because a tree's use of water and its rate of photosynthesis are closely related. These strongly coupled processes serve as the basis of how scientists predict the effects of a warmer Australia on trees and forests.

Sustained evaporative water loss from tree canopies, in essence, serves as a natural cooling mechanism not only for the trees, but also the surrounding environment. This helps mitigate ground level temperatures that would rise rapidly in the absence of tree cover during heatwaves.

Earth system models, particularly those that simulate the exchange of carbon dioxide and water vapour between the land surface and the atmosphere, will need to be revisited in light of these findings. These models are used to forecast climate change impacts, including those of heatwaves, now and in the future.

This study has pinpointed important questions for further research, including how widespread this cooling mechanism is among other tree species, whether or not trees sustain the cooling response under longer and more frequent heatwaves, and what happens under prolonged drought.

These findings build upon the team's prior research on climate warming impacts in eucalypts. Taken together, their findings reveal a prominent role of physiological acclimation to temperature in underpinning the resilience of eucalypts to cope with climate warming. Temperature acclimation is manifested as dynamic fine-tuning of metabolic and physiological processes in response to changes in temperature in the environment. That research published in a pair of papers in the journal *New Phytologist* revealed that temperature acclimation of carbon and water exchange buffers trees against abrupt climate-induced shifts in function expected with climate warming.