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HOW THE MIGHTY ARE FALLEN

From the kings of the jungle to the boreal giants, the world's greatest trees are in trouble, says **William Laurance**

"Going up that river was like travelling back to the earliest beginnings of the world, when vegetation rioted on the earth and the big trees were kings"
Joseph Conrad, Heart of Darkness

BIG TREES have ruled the Earth for at least 100 million years, but their time at the top might be coming to an end as they succumb to climate change, pestilence and other modern maladies.

Big trees are among the largest organisms on earth and are incredibly important ecologically. They help define the architecture of forests and store much of the world's biomass, locking up billions of tonnes of carbon that might otherwise escape into the atmosphere. Their roots can penetrate deep underground to tap hidden water sources and they produce much of the life-giving water vapour that emanates from forests.

Large trees sustain countless other species. Their hollows and crevices provide shelter for myriad animals and their trunks and branches can become gardens, festooned with ferns, ›

orchids, bromeliads and other epiphytes, coated with mosses and lichens and draped with vines. With their tall canopies basking in the sun, big trees capture vast amounts of energy. This allows them to produce massive crops of fruits, flowers and foliage that sustain much of the animal life in the forest.

Big trees also produce the lion's share of seeds and offspring that grow up to become the next generation. And via their sheer size and ceaseless appetite for light, water and nutrients, they have a large competitive effect on local plant communities. Forget lions – big trees are the true kings of the jungle.

Only a small number of tree species have the genetic capacity to grow really big. The mightiest of all are native to North America but big trees are found all over the world, from the tropics to the high-latitude boreal forests.

To achieve giant stature, a tree needs three things: the right place to establish its seedling, good growing conditions and lots of time with low adult mortality. Disrupt any of these three, and you can lose your biggest trees.

In some parts of the world, populations of big tree species are dwindling because their seedlings can't survive or grow. In southern India, for instance, an aggressive alien shrub, *Lantana camara*, is invading the understorey of many forests. Lantana grows in thickets so dense that young trees often fail to take root. With no young trees to replace them, it is only a matter of time before most of the big trees disappear (*Journal of Tropical Ecology*, vol 27, p 365). Across much of northern Australia, gamba grass from Africa (*Andropogon gayanus*) is overrunning native savanna woodlands. The grass grows up to 4 metres tall and burns fiercely, creating super-hot fires that cause catastrophic tree mortality (*Diversity & Distributions*, vol 16, p 854).

Without the right growing conditions trees can't get really big, and there is some evidence to suggest tree growth could slow in a warmer world, particularly in environments that are already warm. Working for decades at La Selva Biological Station in Puerto Viejo de Sarapiquí, Costa Rica, David and Deborah Clark and colleagues have shown that tree growth there declines markedly in warmer years (*Global Change Biology*, vol 16, p 747). "Trees are probably getting a double-whammy when the thermometer rises," says David Clark. "During the day, their photosynthesis shuts down when it gets too warm, and at night they consume more energy because their metabolic rate increases, much as a reptile's would do when it gets warmer." With less energy being produced in warmer years and more being consumed just to survive, there is less energy available for growth.

"Via their sheer size and ceaseless appetite for light, water and nutrients, big trees have a huge impact"

The Clarks' hypothesis, if correct, means tropical forests could shrink over time. The largest, oldest trees would progressively die off and tend not to be replaced. Alarmingly, this might trigger a positive feedback that could destabilise the climate: as older trees die, forests would release some of their stored carbon into the atmosphere, prompting a vicious circle of further warming, forest shrinkage and carbon emissions.

Another study led by Ken Feeley of Wake Forest University in Winston-Salem, North Carolina, found that tree growth rates were declining in Panama and Malaysia (*Ecology Letters*, vol 10, p 461).

Not everyone accepts that tree growth is slowing, however. Some, such as ecologist Oliver Phillips at the University of Leeds, UK, argue that growth across much of the world is accelerating, possibly driven by rising CO_2.

Even so, big trees face threats from elsewhere. The gravest is increasing mortality, especially of mature trees. To become giants, most species need to grow for a very long time. Some big trees are positively ancient. Using radiocarbon dating, Jeff Chambers and colleagues at the University of California, Santa Barbara, showed that large canopy trees in Amazonia ranged from 400 to 1400 years old (*Nature*, vol 391, p 135). In North America, giant redwoods can exceed 2000 years of age and giant sequoias 3000 years.

Across much of the planet, old-growth forests have been cleared for human use. In western North America, most have been replaced by monocultures of fast-growing conifers. Siberia's forests are being logged at a rampant rate (*Trends in Ecology & Evolution*, vol 24, p 541). Logging in tropical forests is selective but the timber-cutters usually go after the biggest and oldest trees.

Even where native forests persist, big trees

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Bark beetles, which invade trees and devour them from within, are on the increase....

... as are vine-like tropical tree stranglers called lianas

are struggling. In the Amazon, my colleagues and I found the mortality rate for the biggest trees had tripled in isolated patches of rainforest surrounded by pastures (*Nature*, vol 404, p 836). This happens for two reasons. First, as they grow taller, big trees become thicker and less flexible, making them vulnerable to wind damage. Forest fragments are acutely susceptible because winds can accelerate over the surrounded cleared lands before slamming into them.

A long, dry death

Second, rainforest fragments dry out when surrounded by hot, dry pastures and the resulting drought stress can kill big trees (*Biological Conservation*, vol 143, p 2763). Tall trees already struggle to transport water from the soil all the way up to their canopy foliage – a distance of 50 metres or more. As the soil dries out, bubbles can form in their water-carrying xylem tissues, blocking the upward flow of water and eventually killing the tree.

Long-term studies in Africa, Central America and the Amazon have shown many large trees succumbing to severe droughts. Many ecologists are surprised at just how devastating droughts can be for big trees. "Old trees must have survived numerous droughts over the centuries, but more recent, harsh droughts are killing lots of them," says Richard Condit of the Smithsonian Tropical Research Institute in Panama.

Their high susceptibility is shown most clearly by an experiment in the Amazon, where researchers created an artificial drought over a 1-hectare forest plot, using a duct

system that drained away about a third of all rainfall – comparable to a moderate drought(*Ecology*, vol 88, p 2259). During their four-year study, death rates doubled for smaller trees but shot up 4.5 times for the bigger canopy trees.

Could global warming bring an increase in droughts? "It's certainly possible," says forest ecologist Simon Lewis of the University of Leeds. "And if extreme droughts do occur then the impacts would be scary." Certain areas of the Amazon periodically suffer from El Niño-driven droughts, but in 2005 and 2010 intense droughts hit even the wettest, least drought-prone parts of the basin. These droughts had a different cause: unusually warm Atlantic sea-surface temperatures, which shifted the rain-bearing inter-tropical convergence zone northward. As Lewis and colleagues showed, the droughts killed tens of millions of trees, which release billions of tonnes of CO_2 into the atmosphere as they decay (*Science*, vol 323, p 1344 and vol 331, p 554).

Changing climates could hurt big trees in other ways too. In rainforests, droughts promote surface fires that burn through leaf litter on the forest floor. Larger trees were initially thought to survive these low-intensity fires but in fact, many die two to three years afterwards (*Ecology Letters*, vol 6, p 6). In cloud forests, trees use their branches and crowns to rake the mist and capture water droplets. Global warming could push clouds up to higher elevations, depriving trees of a crucial source of moisture. If warming increases the intensity of hurricanes and cyclones, expect big trees, which have the tallest and least-flexible trunks, to suffer the most.

Finally, the enemies of big trees may be on the march. Climbing woody vines known as lianas are important parasites of tropical trees. They reduce tree growth and survival, and have a particular propensity for older trees. Lianas proliferate in disturbed forests but now seem to be invading undisturbed forest, too, possibly because they thrive in higher CO_2 levels (*Nature*, vol 418, p 770).

Even worse enemies are insects and diseases. Across vast swathes of western North America, increasingly mild winters are favouring massive outbreaks of bark beetles that can kill entire stands of trees (*New Scientist*, 5 November, p 38). In North America and Europe, exotic pathogens such as Dutch elm disease have killed millions of stately trees that once graced forests and cities. As a result of modern humankind's incredible mobility, such pestilences reach even the remotest corners of the world.

Big trees are adapted for stability and longevity. For long-lived species, demographic models suggest that even a small but persistent increase in adult mortality can seriously erode their population. Whether hit by subtle afflictions or the ecological equivalent of a sledgehammer blow, big trees seem to be suffering almost everywhere.

The decline of big trees foretells a different world where ancient behemoths are replaced by short-lived pioneers and generalists that can grow anywhere, where forests store less carbon and sustain fewer dependent animals, where giant cathedral-like crowns become a thing of the past. ■

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