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ECOLOGY

Drought in the Congo Basin

A remote-sensing analysis of tropical forests in the Congo Basin that are experiencing chronic drought reveals consistent patterns of reduced vegetation greenness, increased temperatures and decreased water storage.

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The response of tropical forests to drought is a topic of considerable research and public-policy interest, and has been identified as a possible tipping point in Earth's climate system[1]. Drought in tropical forests has seasonal, episodic and chronic aspects; although seasonal and episodic events have been broadly studied for the Amazon tropical forests[2–8], chronic drought has received less attention, mainly because of the challenges involved in detecting long-term drought trends[9]. In a paper published on *Nature*'s website today, Zhou *et al.*[10] have significantly expanded the tropical-forest research programme by focusing on chronic drought in Africa's Congo Basin, a region that has been the subject of much less investigation than the Amazon.

Many tropical forests cannot be classified as classic 'rainforests' because they experience seasonal drought (generally defined as less than 100 millimetres of precipitation per month for 1–5 months per year). Trees in such forests are adapted to seasonal drought, and a few months of reduced precipitation have little effect on forest structure. By contrast, episodic events such as the Amazon mega-droughts of 2005 and 2010 can push tropical-forest trees outside their adaptive envelopes, resulting in mortality that is extensive enough to affect the atmospheric exchange of carbon, water and energy[4–6]. However, if the time between these episodic events is long enough, the forests may experience little overall change. Of most concern for tropical forests is chronic drought or frequent extreme drought, and climatic shifts to new, drier states.

Zhou and colleagues describe a study that uses optical, microwave and gravity remote-sensing data to evaluate long-term drought response in the Congo Basin (Fig. 1). Annual precipitation in this region is bimodal, and the authors focused on the second precipitation peak, which occurs between April and June. Rainfall data, including historical information from as far back as 1950 and more-recent data from the Tropical Rainfall Measuring Mission, reveal a steady decline in precipitation since 1985, and the authors report consistent observations of accompanying ecological changes. Reductions in the enhanced vegetation index (EVI; a measure of photosynthetic capacity, or 'greenness', obtained by the MODIS satellite-borne sensor) are reinforced by declines in vegetation optical depth (an indication of the leafy and woody components of living biomass), increases in land-surface temperature, declines in terrestrial water storage and changes to forest structure indicated by microwave backscatter. Increased photosynthetically active radiation (the amount of light available for photosynthesis) and decreased cloud optical thickness completed the picture of a tropical region experiencing decreased rainfall, decreased cloud cover and increased solar radiation for more than a decade.

The consistency in all of these remotely sensed measures of drought contrasts with the more complex story in the Amazon. Field observations[5], land-surface temperatures[11] and radar-backscatter data[6] suggest declines in Amazon productivity during the 2005 mega-drought. And yet EVI analysis frequently indicated greening during Amazon mega-droughts[3,7], suggesting increased productivity[9]. These contrasting observations have led to considerable controversy regarding forest response to drought and potential artefacts in EVI.

Such artefacts stem from the fact that, although optical remote-sensing platforms measure changes in surface reflectance, the signal received by the sensor is also affected by atmospheric features, such as clouds and aerosols, and by changes in the orientation of the sensor with respect to the Sun (and associated shadowing). If the Sun is directly behind the sensor during imaging, shadows are minimized, and the shadow fraction increases at larger Sun–sensor angles. Such changes in Sun–sensor geometry can lead to false interpretations of changes in signal strength and drought response. For example, EVI has been shown to be highly sensitive to increased forest reflectivity, independent of changes in forest leaf area[2], and changes in EVI can be replicated by seasonal changes in Sun–sensor geometry[12].

Several factors may contribute to the differences between Zhou and colleagues' observations in the Congo and the more controversial reports from the Amazon. One probable influence is the duration of the drought: Zhou *et al.* studied a chronic and increasingly severe water shortage, whereas whether the Amazon is also experiencing a long-term drying trend remains an open question[9]. However, analysis[8] using improved data for EVI and for the

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Figure 1 | Long-term drying. Tropical forests in the Congo Basin are experiencing chronic and increasing water shortage.

normalized difference vegetation index do in fact show large-scale 'browning' (reduction in greenness) in the Amazon in the mega-drought years of 2005 and 2010, and these observations are consistent with reduced microwave backscatter[6]. Thus, it seems plausible that the Amazon, like the Congo, has experienced large-scale structural responses to drought events, but that this was masked by remote-sensing artefacts.

Another crucial question is: what actually happens in the forest to cause these remotely sensed signals? The sensors generally respond to changes in the upper forest canopy, and those signals are not simple proxies for whole-ecosystem responses. To cause shifts in forest structure that drive climate-relevant atmospheric exchanges of carbon, water and energy, reductions in photosynthetic capacity must also cause other changes, such as reduced biomass production and elevated tree mortality.

One expected response to a long-term drying trend is a transition from high-biomass, closed-canopy forests to more-open, low-biomass forests and savannahs. However, the thresholds in water stress, carbon starvation, elevated temperature and increased vapour-pressure deficit at which this transition will occur are not well understood[13]. Response to drought is also not limited to upper-canopy effects, and other tools, such as tower-based measurements of evapotranspiration and net ecosystem productivity[14], coupled with field investigations of key ecosystem processes[15], are needed for complete assessments of the effects of drought on net forest–atmosphere fluxes.

Thus, a key constraint on our ability to interpret signals acquired by remote-sensing platforms is a lack of ground-based data with which to validate them. Obtaining such data will require extensive fieldwork using an array of methods at varying scales. As our climate continues to warm, quantifying the effects of drought on forests will become increasingly important, so ground-validated remote-sensing investigations must also be designed that best inform the development of Earth-system models. ■

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