CRITICAL ZONE

The bedrock of forest drought

Bedrock composition can play a critical role in determining the structure and water demand of forests, influencing their vulnerability to drought. The properties of bedrock can help explain within-region patterns of tree mortality in the 2011–2017 California drought.

Christina Tague

Montane forests are iconic natural resources that provide habitat, carbon sequestration, regulation of water, and, for many cultures, profound meaning. A warming climate and prolonged droughts threaten these forests, as shown by the 2011–2017 drought in California, USA, which killed over 140 million trees. However, the vulnerability of forests to climate-driven risks is not evenly distributed across these landscapes. In the 2011–2017 drought, some contiguous forested areas (or forest stands) suffered more than 70% mortality while forests in other locations experienced few or no losses[1]. Understanding these spatial patterns is critical for the projection of future risks and for targeted forest management. Writing in *Nature Geoscience*, Callahan and colleagues look beneath the surface at the composition of bedrock and find a link to these patterns of drought mortality in the California Sierra[2].

Drought-driven forest mortality is patchy; some communities of trees die while others do not (Fig. 1). In the 2011–2017 California drought, higher rates of mortality were experienced by low-elevation forests[3] and regions where evaporative water loss exceeded availability[1]. These regional-scale mortality patterns can be explained by climate variables, including temperature, vapour pressure deficit and precipitation, which change with elevation and latitude in the California Sierra. Explaining patterns within these broad regional climatic gradients, however, is more challenging.

Forested sites with densely packed, tall trees can show greater vulnerability to drought[4], which may seem counterintuitive at first. Their more productive growth often indicates a site with additional moisture that can support greater biomass through long dry summers, and it might be expected that a forest with more available water would show less drought vulnerability. However, highly productive, high biomass forests actually require more water and are therefore at higher risk when droughts do occur. This elevated drought risk, termed structural overshoot — or 'too much of a good thing' — has been documented by empirical studies[5] and by mechanistic models[6]. Questions, however, remain. What drives the observed variation in pre-drought biomass for forests that experience similar climates? And what do those differences mean for the risk of drought-related mortality?

Fig. 1 | Forest mortality in the California Sierra following the 2011–2017 California drought. While regional-scale variations in tree mortality may be explained by climate variability, Callahan et al. show that bedrock geology and porosity can contribute to explaining within-region patterns of mortality. Credit: Janet Choate, TagueTeamLab.

Callahan and colleagues focus on three forested sites within mid-elevation California Sierra forests that experience similar precipitation, snowmelt timing, temperature and vapour pressure deficit — the primary climate drivers for forest water use and growth. Using satellite remote-sensing data, they show that forest biomass was remarkably different across the three sites prior to the 2011–2017 drought, despite a similar climate. Following that drought, the site with denser forests showed substantially greater declines in greenness, a remote-sensing-based proxy for mortality, demonstrating structural overshoot. Using seismic refraction surveys to look into the subsurface, Callahan and colleagues show that a key difference between the sites is the ability of the shallow subsurface to store water.

The most densely forested site had a pore volume more than five times greater than the least densely forested site, suggesting that the more vulnerable location actually had greater water storage capacity. In systems like the California Sierra, where most precipitation falls during the winter, the ability for trees to use stored water to support productivity during the growing season is critical. So, although greater water storage allows trees to support more biomass in most years, this greater biomass can also exacerbate the vulnerability of these more productive forests during multi-year droughts, when precipitation may not be enough to refill the subsurface storage.

The greater storage capacity observed in the more densely forested study site offers a compelling explanation for the cross-site differences in forest productivity. However, there are other geological differences between the sites — notably the composition of bedrock material. The differences in bedrock material that give rise to differences in storage capacity also yield differences in nutrient concentration. The study site with higher storage capacity was also more nutrient-rich, which Callahan and colleagues suggest may also play a role in greater pre-drought productivity and biomass.

At the scale of the entire California Sierra, climate is the primary driver of forest productivity, but within individual climate zones bedrock heterogeneity may dramatically shape forest productivity and vulnerability to drought. Callahan and colleagues present a compelling illustration of how geology matters to forests in times of drought, but it's a complex picture that is far from complete. The substantial latitudinal and elevation gradients within the California Sierra provide a wide range of pre-drought climates — on which geology is superimposed. The effect of storage and nutrient availability is likely to vary with these gradients as well as with other factors, including disturbances such as fire and disease, also species distributions and their adaptations to climate. It is also important to consider that the 2011–2017 drought was a single event — more analysis is needed to determine how warmer, longer or more frequent droughts may alter the spatial patterns of mortality. Finally, from a forest-management perspective, it will be important to consider whether a low-severity fire or active management of forest density might have been sufficient to reduce the structural overshoot.

Projecting what forests in California and around the world may look like in the next decades, and understanding how to manage them, requires thorough understanding of how the biosphere interacts with climate. Callahan and colleagues provide a timely reminder to also look beneath the surface at the role played by bedrock geology. Only by integrating the lithosphere into our understanding of forest vulnerability to drought can we hope to understand and, where possible, mitigate forest mortality risks. ❐

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Competing interests
The author declares no competing interests.

CONTINENTAL CRUST

Plant fingerprints in the deep Earth

The colonization of Earth landmasses by vascular plants around 430 million years ago substantially impacted erosion and sediment transport mechanisms. This left behind fingerprints in magmatic rocks, linking the evolution of Earth's biosphere with its internal processes.

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How Earth's internal processes impacted the evolution of its biosphere in deep time, and in what way the interaction between these different reservoirs is responsible for Earth habitability, remains debated. For instance, it isn't clear[1–4] if the oxygenation of Earth's atmosphere was triggered by modifications in its geosphere and/or biosphere. Improving our knowledge on how a changing geosphere impacts the biosphere, and vice versa, is therefore of paramount importance for a better understanding of our planets past and the reasons for its long term habitability. Writing in *Nature Geoscience*, Spencer and colleagues[5] describe a change in the correlation between the oxygen (O) and hafnium (Hf) isotopic signatures of zircon grains that are younger than 430 million years, an age contemporaneous with the spreading of vascular plants on Earth. They attribute this observation to a change in the composition of sedimentary material recycled into the deep Earth within subduction zones, mediated by the newly developed biosphere on the continents.

The evolution of land plants started between the middle Cambrian and early Ordovician, some 515 to 470 million years ago[6]. The coverage of the continental crust with plants strongly influenced Earth surface processes by intensifying dissolution and chemical weathering of minerals, enhancing clay formation and impacting the morphology of river systems[7,8] (Fig. 1). The effect of land plants on the erosion of the continents and the sedimentary routing system is exemplified by the strong increase in the abundance of mudstone around 450 to 430 million years ago[9], and by the circumstance that flood plains and meandering rivers started to appear in the geological record around the same time that vascular plants evolved[8].

Part of the sedimentary material that is produced by the physical and chemical erosion of the continental crust is deposited on the ocean floor and subsequently transported to subduction zones where it eventually reintegrates with the magmatic cycle. Thus, Spencer and colleagues set out to investigate if the major changes in Earth surface processes that were triggered by land plants, left behind chemical fingerprints in