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Climate Matters

News from the USGS Climate Research & Development Program

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Volume 4, Winter 2016

Leaf to Landscape: Understanding and Mapping Forest Vulnerability to Hotter Droughts

"Hotter droughts" (also called "global-change-type droughts" or "hot droughts") are an emerging but poorly-understood climate-change threat to forests worldwide. USGS scientists and their collaborators are using California's recent hotter drought (2012-2015) as a preview of the future, gaining the information needed to help forest managers adapt to a warming world.

Background and need

We usually think of droughts as periods of low water supply (precipitation), but often overlook the other side of the equation: atmospheric water demand (the drying power of the atmosphere). For example, if we look only at precipitation records, California's recent drought would rank as severe but not unprecedented; comparable periods of low precipitation occurred during the dust bowl era of the 1920s and 1930s. However, compared to the dust bowl era, temperatures during the 2012-2015 drought averaged about 1º C warmer, which significantly increased the atmosphere's evaporative demand for water and easily made this the most severe drought in California's 120-year instrumental record, and perhaps much longer. Additionally, water supplies for California's cities, agriculture, industry, and forests all depend on the accumulation of a thick mountain snowpack each winter, which then melts and slowly releases water during the otherwise dry summer months. But the higher temperatures of the recent drought meant that virtually no snow accumulated during the winter, and the little bit that did accumulate melted far earlier than usual in the spring.

The effects of California's drought on forests, particularly in the Sierra Nevada mountain range, have been extreme. U.S. Forest Service experts have estimated that, by the summer of 2015, tens of millions of trees had died, most of them in lower-elevation forests (Figure 1). Virtually no species has been spared, with substantially elevated mortality recorded in pines, firs, incense cedars, and oaks. A glaring exception has been the iconic giant sequoias; only a handful of sequoias have died, and those that died usually already had fire scar damage at their bases, which likely reduced their ability to transport

Figure 1. California's hotter drought has already killed millions of trees, particularly in low-elevation forests. (Photo credit: N. Stephenson, USGS)

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water to their crowns. But even though most sequoias have survived the drought, many have experienced unprecedented foliage die-back (Figure 2). By systematically shedding their older leaves, sequoias have conserved water by reducing the leaf area that is exposed to the drying power of the atmosphere.

Figure 2. Giant sequoias have fared better than other tree species, but many have shown unprecedented foliage dieback in response to the drought. (Photo credit: N. Stephenson, USGS)

If Earth continues to warm as projected, forests will experience hotter droughts that are both more frequent and more severe. Fortunately, managers are not helpless in the face of such changes; they can increase forest resistance to (ability to survive) hotter droughts. For example, forests can be thinned – usually by prescribed fire or mechanical thinning that selectively removes smaller trees – to reduce competition for water among the remaining trees. But the task is so vast that forest managers must perform triage, deciding where on the landscape their limited funds will be best applied. They thus need reliable forest vulnerability maps to help them strategically target their treatments, and to help them plan appropriate responses to future forest die-offs in highly vulnerable areas that they are not able to treat.

The Leaf to Landscape project

Using California's hotter drought as a potential preview of the future, USGS Climate Research & Development Program scientists, working with a number of collaborators and stakeholders, have helped catalyze the Leaf to Landscape project. Leaf to

Landscape has two broad, complementary goals. First, it aims to provide empirically-derived maps of forest vulnerability to hotter droughts for large parts of California, letting the trees themselves reveal which parts of the landscape are most and least vulnerable. Second, it aims to improve our basic mechanistic understanding of forest vulnerability to hotter droughts, providing the grist for models with applications well beyond California.

To reach these ends, Leaf to Landscape has three main components, designed to be integrated across scales – from tree leaves to entire forests. The first is tree physiology during drought, spanning about 10 dominant species. Individual trees are climbed by professional climbers, and small branches are cut from high in their crowns (Figure 3). Back on the ground, one or more small branches are immediately

Figure 3. A University of California, Berkeley scientist climbs a giant sequoia to sample branches from high in its crown. (Photo credit: A. Ambrose, UC Berkeley)

inserted in a pressure chamber to quantify the degree of drought stress experienced by each tree (Figure 4). The remaining branch samples are then transported to a laboratory where leaf water content and other chemical markers – which together can provide insight into a tree's level of drought stress – are quantified.

Figure 4. A pressure chamber is used to record how much pressure is required to squeeze water out of a small sequoia branch – a measure of the drought stress experienced by the sequoia. (Photo credit: A. Ambrose, UC Berkeley)

These measurements of drought physiology are strategically co-located with the second component of Leaf to Landscape: tree population monitoring. USGS maintains the world's longest annual-resolution forest dynamics dataset, having annually tracked the health and fate of each of some 30,000 trees for up to 34 years (Figure 5).

Figure 5. USGS biologists assess the health of a white fir, one of tens of thousands of individual trees whose fates have been tracked annually throughout the drought. (Photo credit: USGS)

These data provide an invaluable long-term baseline of forest health, dynamics, and agents of tree mortality during "normal" forest conditions. Continued monitoring throughout the drought provides key information on the timing and proximate causes of tree mortality. Adding to these data, foliage dieback in giant sequoias is now monitored annually.

Both of the preceding components – tree drought physiology and population monitoring – provide essential calibration and validation for the third component: remote sensing (Figure 6). Remote sensing allows scientists to map forest drought responses over broad landscapes. High-resolution LiDAR is used to create a detailed three-dimensional map of

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Figure 6. An aircraft captures high-resolution LiDAR and hyperspectral images of forests during the drought. (Photo credit: G. Asner, Carnegie Institute of Science)

tree crowns for millions of trees. The spectral reflectance of each tree crown is also recorded, allowing identification to species and measurement of whole-crown water content (Figure 7) and chemical signatures (such as nitrogen and non-structural carbohydrates) that may be related to tree health and drought stress.

The Leaf to Landscape project has successfully completed all three of these data collection components during its first full year. Reflecting the interdisciplinary nature of the work, funding and in-kind

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contributions came from USGS, the National Park Service, the U.S. Forest Service, Stanford University/ Carnegie Institute of Science, and the University of California, Berkeley.

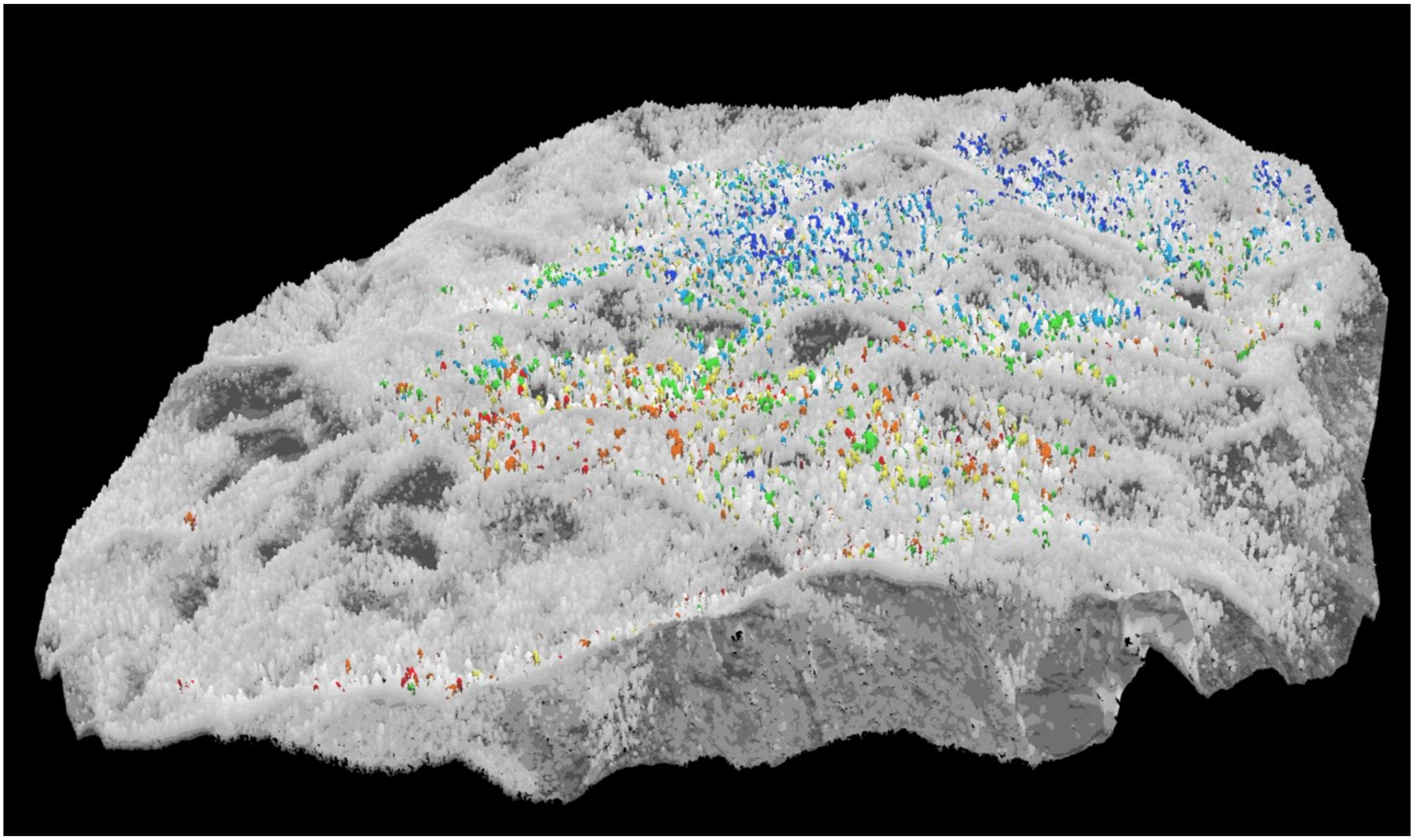

Figure 7. Remote imagery reveals a pronounced spatial gradient in the whole-crown water content of individual giant sequoias during the drought. Warmer colors indicate lower water content. (Credit: G. Asner, Carnegie Institute of Science)

Data analyses are underway, but early results from giant sequoias may give hints of findings to come. Remote sensing reveals substantial spatial variation in sequoias' whole-crown water contents (Figure 7). In contrast, direct ground-based measurements show very little spatial variation in sequoias' leaf water content or drought stress. The apparent paradox might be explained by spatial variation in whole-crown leaf area; that is, sequoias might maintain favorable water status by adjusting their total leaf area. Low leaf area could reflect responses to acute drought (i.e., sequoias abruptly reduce their leaf area by shedding older foliage) and/or long-term adjustments to sites with chronically low water supplies (i.e., sequoias never develop a large total leaf area). Much work remains to be done, but, at least for sequoias, total crown water content during the current drought might prove to be an indicator of site vulnerability to hotter droughts of the future.

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Future directions

Fortunately, California is poised to get some relief from its crippling drought. Sea-surface temperatures in the tropical Pacific reflect one of the strongest El Niño events in the historical record, and strong El Niños typically bring heavy precipitation to most of California.

Even if the current El Niño is followed by several more wet years, thus signaling the end of the drought, the Leaf to Landscape project's efforts to understand forest vulnerability to hotter droughts will continue, especially to document and understand lagged drought effects and forest recovery. For example, anecdotal accounts suggest that tree mortality remains elevated for one or more years following drought. Leaf to Landscape will quantify the magnitude and duration of lagged tree mortality, and will determine the agents contributing to it (such as insects and pathogens). The project will also document the rate and magnitude of tree crown recovery – leaf area, water content, and chemistry – and interpret its relationship to tree growth and mortality.

The team will also complete maps of forest vulnerability for large sections of California, passing the information to land managers and helping with interpretation. The Leaf to Landscape project promises to improve our basic understanding of an emerging climate change phenomenon, with broad implications and applications.

For more information, contact Nate Stephenson

Further reading:

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