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Leaf to landscape responses of giant sequoia to hotter drought: An introduction and synthesis for the special section

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ABSTRACT

Hotter droughts are becoming more common as climate change progresses, and they may already have caused instances of forest dieback on all forested continents. Learning from hotter droughts, including where on the landscape forests are more or less vulnerable to these events, is critical to help resource managers proactively prepare for the future. As part of our Leaf to Landscape Project, we measured the response of giant sequoia, the world's largest tree species, to the extreme 2012–2016 hotter drought in California. The project integrated leaf-level physiology measurements, crown-level foliage dieback surveys, and remotely sensed canopy water content (CWC) to shed light on mechanisms and spatial patterns in drought response. Here we summarize initial findings, present a conceptual model of drought response, and discuss management implications; details are presented in the other four articles of the special section on Giant Sequoias and Drought. Giant sequoias exhibited both leaf- and canopy-level responses that were effective in protecting whole-tree hydraulic integrity for the vast majority of individual sequoias. Very few giant sequoias died during the drought compared to other mixed conifer tree species; however, the magnitude of sequoia drought response varied across the landscape. This variability was partially explained by local site characteristics, including variables related to site water balance. We found that low CWC is an indicator of recent foliage dieback, which occurs when stress levels are high enough that leaf-level adjustments alone are insufficient for giant sequoias to maintain hydraulic integrity. CWC or change in CWC may be useful indicators of drought stress that reveal patterns of vulnerability to future hotter droughts. Future work will measure recovery from the drought and strengthen our ability to interpret CWC maps. Our ultimate goal is to produce giant sequoia vulnerability maps to help target management actions, such as reducing other stressors, increasing resistance to hotter drought through prescribed fire or mechanical thinning, and planting sequoias in projected future suitable habitat, which may occur outside current grove distributions. We suggest that managers compare different types of vulnerability assessments and combine vulnerability maps with other sources of information to inform decisions.

1. Introduction

As climate change progresses, policy makers and resource managers will be increasingly challenged to decide how and where to invest scarce resources to address conservation needs. The geospatial pattern of climate change vulnerability, including the location of climate change refugia, can help managers prioritize where on the landscape to apply conservation actions (Ashcroft et al., 2009; Glick et al., 2011; Keppell et al., 2015; Klausmeyer et al., 2011; Morelli et al., 2016; Tingley et al., 2014). Model projections of future climate change often are used to drive such vulnerability assessments (Carroll et al., 2015; Thorne et al., 2017), but managers may be hesitant to apply model results when making place-based decisions due to the uncertainties inherent in the models (Gray, 2011; Kujala et al., 2013; Michalak et al., 2017). This has been our experience working with managers in national parks and national forests in the southern Sierra Nevada (Nydick and Sydoriak, 2014).

We propose empirical measurements of drought response as a promising alternative method to map climate change vulnerability for forests (Verbesselt et al., 2016). As temperatures warm, droughts are

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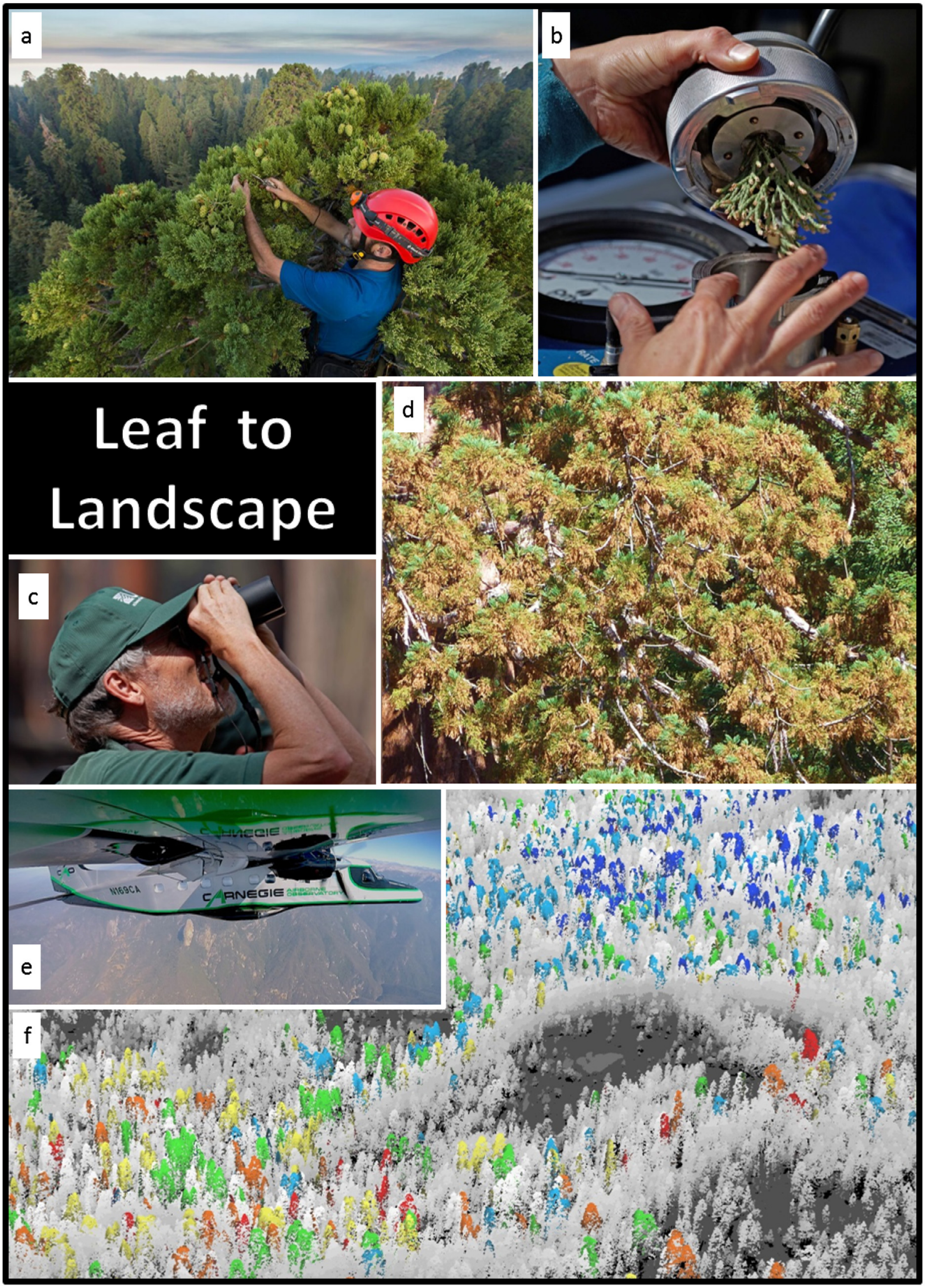

Fig. 1. Leaf to Landscape measurements across three spatial scales. (a and b) Climbers collected giant sequoia foliage for leaf-level analyses in 49 trees (photos: Lincoln Else, Anthony Ambrose); (c and d) Surveyors documented percent foliage dieback along trail corridors in eight sequoia groves (photos: Anthony Ambrose, Nate Stephenson); (e) Carnegie Airborne Observatory (CAO) flights captured LiDAR and imaging spectroscopy data across 38 groves (photo: Greg Asner); and (f) canopy water content (CWC) was mapped for giant sequoia crowns (high CWC is blue; low CWC is red; image: Greg Asner). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)