Understanding the patterns and processes of tree mortality at multiple spatial scales in a California coastal pine forest

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Project Objectives

In recent decades, trees have been dying at alarming rates in forests across the western United States (van Mantgem et al. 2009). Many studies have demonstrated that widespread tree mortality is induced by drought stress (Breshears et al. 2005). If the western U.S. becomes warmer and drier, as current climate models project, rates of tree mortality will likely increase. However, our current knowledge of forest sensitivity to drought is limited to areas with continental, montane climates; we know relatively little about tree mortality in coastal forests.

The unvarying nature of coastal climates has traditionally been assumed to buffer coastal vegetation from large climate fluctuations. However, following extreme drought in southern California in two of the last four years, when fewer than 25 cm of rain fell (median annual rainfall is 40-45 cm), widespread mortality of Bishop pine (Pinus muricata D. Don) peaked in 2009 on Santa Cruz Island (SCI)--one of the California Channel Islands (Figure 1). These fog-influenced forests in coastal California are likely to experience a warmer and possibly less foggy future, which places them at higher risk of water stress and drought-induced mortality such as what has happened in recent years (Johnstone and Dawson 2010).

![Figure 1. Normalized Difference Vegetation Index (NDVI) for the Bishop pine stand on SCI during the month of October, for 30 m Landsat Thematic Mapper imagery. NDVI is a commonly used metric of vegetation growth and vigor, and it is used to assess relative levels of vegetation water stress. Values on figure refer to rainfall that water year. This 2005-2009 time series spans the drought period, indicated by below average rainfall between water years 2007 and 2009 (long-term mean rainfall on adjacent Santa Barbara mainland is ~46 cm). Vegetation progressed from unstressed (high NDVI values) in 2005 to high stress (or low NDVI values) by 2009.](image-url)
Mechanistic controls on tree mortality are still poorly understood despite many recorded accounts of large mortality events (McDowell et al. 2008). Soil water status is a basic parameter influencing primary productivity and plant health, but we largely lack a mechanistic understanding of soil moisture controls and certain aspects of plant-soil water relations, which would provide explanatory power to relate soil water deficit to tree mortality. The objective of our research is to advance our understanding of controls on soil moisture that directly impact tree mortality in the maritime climate of coastal California across a variety of spatial and temporal scales. For this study, our aims are to map the current spatial distribution of Bishop pine mortality at the stand-level and to use remotely-sensed data to assess the degree to which landscape and soil attributes are related to mortality patterns and presumably to soil water status. The outcome of this work should elucidate the connection between landscape-scale controls on soil water status and mortality risk at the scale of the individual tree.

**Approach and Procedures**

Small changes in meteorological variables can give rise to large changes in the physiological status of plants on short timescales. Geomorphic attributes, however, can help explain how landscape features impact plant-available soil water throughout the year and across years. In our analysis of the spatial patterns of Bishop pine mortality, we tested whether geomorphic features derived from landscape curvature and drainage networks correlate with the extent of tree mortality.

Remote sensing techniques were used to map the distribution of dead Bishop pines. To isolate the dead Bishop pines, we calculated a vegetation index (Visible Atmospherically Resistant Index, VARI) to detect chlorophyll content in vegetation, i.e., a proxy for productivity, in a high spatial resolution (1 m) color aerial photograph (Digital Orthophoto Quarter Quad, DOQQ) in the year of peak mortality (2009) (Gitelson et al. 2002). We determined a threshold for VARI beyond which the crowns of dead Bishop pines could be identified, which were formerly healthy vegetation as determined in a 2005 DOQQ, the year prior to drought (Figure 2). Spatial clustering of dead Bishop pines was quantified using the GizScore metric, where low values indicate no spatial clustering (congruent with the null hypothesis) and high values indicate clustering.

Two environmental variables were generated as they relate to how topography affects soil moisture at the landscape scale: (1) Topographic Index is calculated from the 1.5 m resolution Light Detection And Ranging (LiDAR) Digital Elevation Model (DEM) as upslope catchment area/ln(slope), and represents where subsurface water would accumulate; (2) Curvature was calculated by taking the second derivative of the slope from the LiDAR DEM. The convergent and divergent areas are expressed in positive and negative kappa values, respectively. Clusters of dead Bishop pines were related to these variables.
Results

Our results show that mortality is concentrated at the eastern margins of the stand and at higher elevations, which is where solar radiation is on average much higher than in other portions of the stand due to lower daytime cloud cover. Dead tree clusters tend to converge with negative values of the TI, which suggests they are on ridges more so than in drainages (Figure 3a). Likewise, dead trees are found on divergent parts of the landscape where water flows off the ridge, as opposed to where it collects in channels (Figure 3b).

Discussion

Remote sensing proved to be a powerful tool for identifying the spatial extent of tree mortality in this rugged and remote location. While the control of topography and geomorphic attributes on soil moisture at a landscape scale cannot be underestimated in this rugged landscape, these features did not fully explain the variation in spatial patterns of current Bishop pine mortality. This analysis elucidated the disproportionate role that climatic factors must have on plant-available water at a landscape scale.

In the Mediterranean climate of coastal California, we know that summer-time stratus clouds ameliorate plant water stress in a number of ways: cloud-shading from overcast reduces potential evapotranspiration, and fog drip and potentially foliar absorption during cloud immersion provide water to plants during the otherwise dry summer months. However, we do not understand how cloud shading and fog immersion separately influence plant water status and thus possible susceptibility of Bishop pines to mortality. One possible impact of climate change will raise summer-time stratus cloud heights and thus reduce immersion but not shading. To directly test the strength of the relationships among summer-time fog drip, fog immersion, and plant water stress, we are conducting a field experiment to compare the physiological response of
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trees, namely stomatal conductance and leaf water potential, between plots where fog drip is excluded and where it is not (control), at two sites that represent end points of a coastal-inland cloud gradient. An improved understanding of how coastal fog-dominated ecosystems in California respond to varying seasonal water inputs is important for predicting potential changes in forest carbon stocks and range shifts in a future climate with less summer fog and higher temperatures.

Our work thus far has addressed an important element of the Kearney Mission by exploring the role of complex topography on soil moisture to help explain tree mortality at a local scale relevant to forests along coastal California. Our ongoing work will improve our mechanistic understanding of tree mortality by examining the response of plant physiology to soil moisture variation as determined by fog-drip and fog immersion. Our research seeks to improve our understanding of how coastal fog-dominated systems respond to varying seasonal water inputs in order to assist management of these forests under future climate conditions that are likely to be drier overall.

**Figure 3.** The spatial pattern of Bishop pine mortality overlaid on the four environmental variables considered in this research. (a) Clusters of dead trees are found where the Topographic Index (TI) is most negative. Negative values of the TI are associated with dry parts of the landscape, such as hillslopes, while positive values of TI indicate stream channels. (b) Similarly, clusters of dead trees appear to be on divergent parts of the landscape, i.e., ridges, indicated by negative kappa values. Positive kappa values indicate convergent parts of the landscape that are often channelized.
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References


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