Impact of Drought on Vegetation in the Tuolumne River Watershed

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**Introduction**

Climate and topography shape community structure and adaptations of the vegetation within the Tuolumne River watershed. Differences in elevation and local climate shape the distribution and abundance of plant species from the Central Valley floodplains to the Sierran alpine zone by altering the availability of water spatially and temporally (Epke et al. 2010). Furthermore, the high elevation, complex topography, and low infiltration makes the Tuolumne river system snowmelt dominated. The forested upland zone of the watershed is dominated by various combinations of ponderosa pine (*Pinus ponderosa*), Jeffrey pine (*Pinus jeffreyi*), sugar pine (*Pinus lambertiana*), Douglas-fir (*Pseudotsuga menziesii*), incense cedar (*Libocedrus decurrens*), California black oak (*Quarcus kelloggi*) and red fir (*Abies magnifica*). These forests experience a Mediterranean climate that brings cold and wet winters and warm and dry summers, but with high inter-annual variability in precipitation rates (Epke et al. 2010). Forested vegetation in water-limited regions such as the upper Tuolumne watershed can provide important ecosystem services by promoting a local community with typically high plant density, biomass, diversity and structural complexity. California's extensive drought from 2012 to 2015 has increased heat stress, weakening individual trees to insect attack, and increased severity and frequency of wildfires, resulting in higher tree mortality rates in the upland Tuolumne coniferous forest zone (Vose et al. 2016).

Forests are critical in affecting quantity and timing of stream flows by intercepting precipitation, influencing groundwater recharge, and providing flood mitigation. Forests can affect streamflow patterns by decreasing surface runoff, snow accumulation, and melting rates, while increasing rates of evapotranspiration. Furthermore, many animal species depend on specific woody vegetation structure for the completion of their life cycle as it acts as a corridor for migration up and down the system. In return, the riparian vegetation can be altered if the habitat cannot sustain populations of pollinators, seed dispersers, or insectivores that keep the system in balance (Vose et al. 2016). Forests have a strong influence in ecosystem composition, water balance, and biogeochemical cycling that shape water quality and biota present in the system.

**Impacts of Drought on Tuolumne Upland Forest**

In the Tuolumne River watershed, the prolonged drought has led to increased tree mortality in the higher elevation alpine zone (Mantgem et al. 2009). Drought is defined as a moisture limitation from below average precipitation, high temperatures, or a combination of both, which leads to a change from the historic climate in the region (Mantgem et al. 2009). High tree density, fire suppression, increased drought conditions, and increased pathogen and insect attack have all increased tree mortality in the region. By tracking 21,338 trees in a network of old-growth forest plots in Sierra Nevada, mortality rate increased significantly over 22 years of measurement, correlating with temperature increase (Mantgem et al. 2009). This loss of vegetation results in reduced water quality, altered riparian habitats, shifted nutrient and water cycling, and increased radiation load, which accelerates climate change and threatens public safety while interrupting access to public roads and utilities (Vose et al. 2016). Furthermore, tree-dieback as a result of drought reduces canopy cover, which alters evaporation, transpiration, and canopy interception that can indirectly alter infiltration, runoff, groundwater recharge, and streamflow rates of the watershed (Adams et al. 2012).

Drought leads to possible direct and indirect contributions to tree mortality while enhancing the growth and reproduction of insects and pathogens that attack trees (Mantgem et al. 2009). Sierra Nevada forests support native levels of a diverse group of bark beetles that have greatly increased in populations in recent years due to prolonged drought. Currently, the drought coupled with high tree density, has accelerated the spread and intensity of attacks by mountain pine beetle, devastating more than 800,000 acres of conifers across the state (Fimrite 2015). Bark beetles feed on the phloem and woody material beneath the bark of these stressed trees. Drought conditions reduce carbon assimilation, uptake of water, and cell turgor, which weakens the mobility of secondary metabolites that could be used as a defense against bark beetle attack (Sala et al. 2012). Furthermore, drought-stressed trees result in an increase in concentration of nitrogen compounds and sugars in plant tissue that attract insect herbivores (Mattson and Scriber 1987). Drought provides an increased source of susceptible host trees, which allows beetle populations to grow and infect these trees, increasing vegetation die-back.

Changes in forest canopy and adaptations to increased temperature and water limitations impact the entire ecosystem. Trees experiencing drought conditions have a number of morphological traits and adaptations that alter biogeochemical cycling. For instance, drought-stressed trees susceptible to herbivory alter the movement of elements, such as carbon, nitrogen, and phosphorus, from plants to the soil affecting the input of organic materials into the system (Vose et al. 2016). Additionally, a severe outbreak of bark beetles led to a decrease in aboveground woody carbon production by 20-60 percent (Bright et al. 2012). Loss of vegetation with increased tree mortality shifts nutrient cycling while increasing melting rate of snow, leading to higher peak flows during the spring melt, thus changing the hydrology of the watershed (Cristea et al. 2013).

Drought conditions lead to an increased frequency and intensity of wildfires, changing nutrient storage and loss from forests (Mantgem et al. 2009). Most of the vegetation in the coniferous forest Tuolumne upland zone have life history strategies adapted to recurring fires, such as serotinous cones, and thick fire-resistant bark with flammable needles high above the ground. Although fires are one of the dominant drivers of ecosystem succession in the Sierras, large and more severe fires caused by years of fire suppression policies, increased drought conditions, and high populations of dead trees kill more of the mature conifers that dominate the upland ecosystem (Epke et al. 2010). The newly exposed soil following severe fire increases the likelihood of nutrient leaching, increasing rates of runoff, and turbidity of the waterways. Furthermore, wildfires release elements, such as carbon and various nutrients derived from live and dead matter, to the atmosphere or in the watershed. Although forest fires play a large role in the Sierran ecosystem, drought increases the likelihood for severe wildfires by creating higher potential for ignition and fire spread (Vose et al. 2016)

**Management**

Forest managers must be able to strike a balance between maximizing forest productivity while minimizing impact on water resources in order to address tree mortality in the Tuolumne watershed. Firstly, a formal task force of federal, regional, and state entities must be formulated to address the underlying causes of tree mortality resulting from drought. Additionally, creating an action plan to identify ways to retain water for forests using forest management strategies is essential for reducing tree mortality. Thinning overcrowded timber stands and reducing water loss by evaporation of the soil through mulching are some ways to manage these damaged forests. Thinning can increase individual tree growth as well as strengthening resilience to droughts, insects, and disease and increasing surface water runoff. Furthermore, the remaining trees are able to take advantage of increased soil moisture availability and expand their roots. It is also important to reduce sediment and nutrient inputs to the stream by planning actions to avoid ground disturbance during low-flow periods and in vulnerable areas (Vose et al. 2016).

Understanding the effects of drought on the upland vegetation assemblage is critical for predicting community shifts and for designing mitigation strategies. Remote sensing techniques can be used to track changes in forest composition and further understand the effects of drought on native tree species. Using satellite imagery, managers can easily monitor changes in forest cover in the Tuolumne watershed. This broader scale imagery identifies areas most affected by drought and therefore may be a higher priority for response. Additionally, metrics such as the Normalized Difference Vegetation Index [NDVI] can aid in monitoring the “greenness”, or intensity and density of vegetation. NDVI is calculated from a combination of infrared and near infrared bands on the satellite imagery and correlates to the relative biomass and chlorophyll absorption of an area’s vegetation. Using these broad-scale vegetation monitoring methods, managers can implement regulatory efforts that address the forest ecosystem as a whole. Through remote sensing, managers can successfully monitor tree mortality and whether or not their mitigation measures are adequate (Vose et al. 2016). Higher frequency and severity of drought conditions calls for understanding and predicting changes to hydrological processes and resulting impacts on vegetation across spatial and temporal scales through the use of adequate monitoring techniques.

## Conclusions

The current prolonged drought has led to higher susceptibility of vegetation to insect attack and increased severity and intensity of wildfires leading to higher tree mortality rates in the upland mixed coniferous zone of the Tuolumne River watershed. These widespread effects require an interdisciplinary approach in research and management, linking forest and aquatic ecosystem responses across spatial and temporal scales to effectively manage and reduce tree mortality rates in the Tuolumne River watershed.

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