United States Department of Agriculture

Drought and Tree Mortality in the Pacific Southwest Region

A synopsis of presentations and work group sessions from the

Science and Management Symposium—Lessons Learned From Extreme Drought and Tree Mortality in the Sierra Nevada: How Can Past Events Inform Our Approach Forward?

Symposium held July 2017, Sacramento, CA

Forest Service Washington Office December 2017 Office of Sustainability and Climate

USDA California Climate Hub
U.S. DEPARTMENT OF AGRICULTURE

Drought and Tree Mortality
in the Pacific Southwest Region

Background

In July 2017, the U.S. Forest Service, Pacific Southwest Region (Region 5) and the U.S. Department of Agriculture (USDA) California Climate Hub co-hosted a two-day symposium on drought and tree mortality. The symposium supported objectives of the ***Interagency National Drought Resilience Partnership*** and the ***State of California drought response effort***. This symposium highlighted the nexus between drought conditions and the extensive tree mortality occurring in the Sierra Nevada. This fact sheet provides a synopsis of presentations and break-out sessions from the symposium.

Drought in California—Ecological Context

Different ecosystems have different capacities to withstand droughts. In addition, the effect of precipitation deficiency is modulated by temperature and the season in which precipitation falls. For example, precipitation deficits were largely responsible for producing the agricultural drought in California, but the effect of high temperatures in high elevation areas during the wet season was also reduced snowpack (Pepin et al. 2015).

California droughts have been well studied. Research on drought event variability, causes, and effects look back as far as medieval times where it is shown that California experienced sustained droughts (Stine 1994). Studies show that by some measures the most recent drought was the most severe in both observational and reconstructed records (Swain et al. 2014, Griffin and Anchukaitis 2014), but by other measures not unprecedented (Diaz and Wahl 2015).

Over the past century, drought frequency has increased (Hughes et al. 1992). In the past 30 years, drought severity, as measured by the Palmer Drought Severity Index (PDSI), has intensified (Figure 1). PDSI is a measurement of dryness based on recent precipitation and temperature (Dai and NCAR 2017).

Definitions of Drought

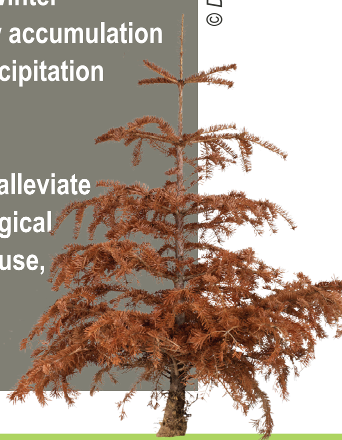
According to the National Drought Mitigation Center, drought originates from an insufficiency of precipitation over an extended time period—usually more than a season—producing a water shortage for some activity, group, or environmental sector. Drought is an issue that periodically affects people and ecosystems across much of the United States. There are many types of drought including:

- *Meteorological* – degree of dryness in weather over a defined period of time;
- *Agricultural* – links meteorological drought with agricultural impacts;
- *Hydrological* – precipitation deficits, with emphasis on effects on the hydrological system (e.g., water storage and flux); and
- *Socio-economic* – demand for economic goods exceeds supply as a result of weather/climate-related shortfall in water supply (Wilhite and Glantz 1985).

In terms of forested and rangeland ecosystems, *ecological drought* is an episodic deficiency in water availability that drives ecosystems beyond thresholds of vulnerability, affects ecosystem services, and triggers feedbacks in natural and human systems (Crausbay et al. 2017).

There is increasing discussion of *snow drought*, defined as a lack of winter precipitation or a lack of snow accumulation during near-normal winter precipitation (Harpold et al. 2017).

Humans also contribute to or alleviate drought by modifying hydrological processes (e.g., through land use, irrigation, and dam building) (Van Loon et al. 2016).



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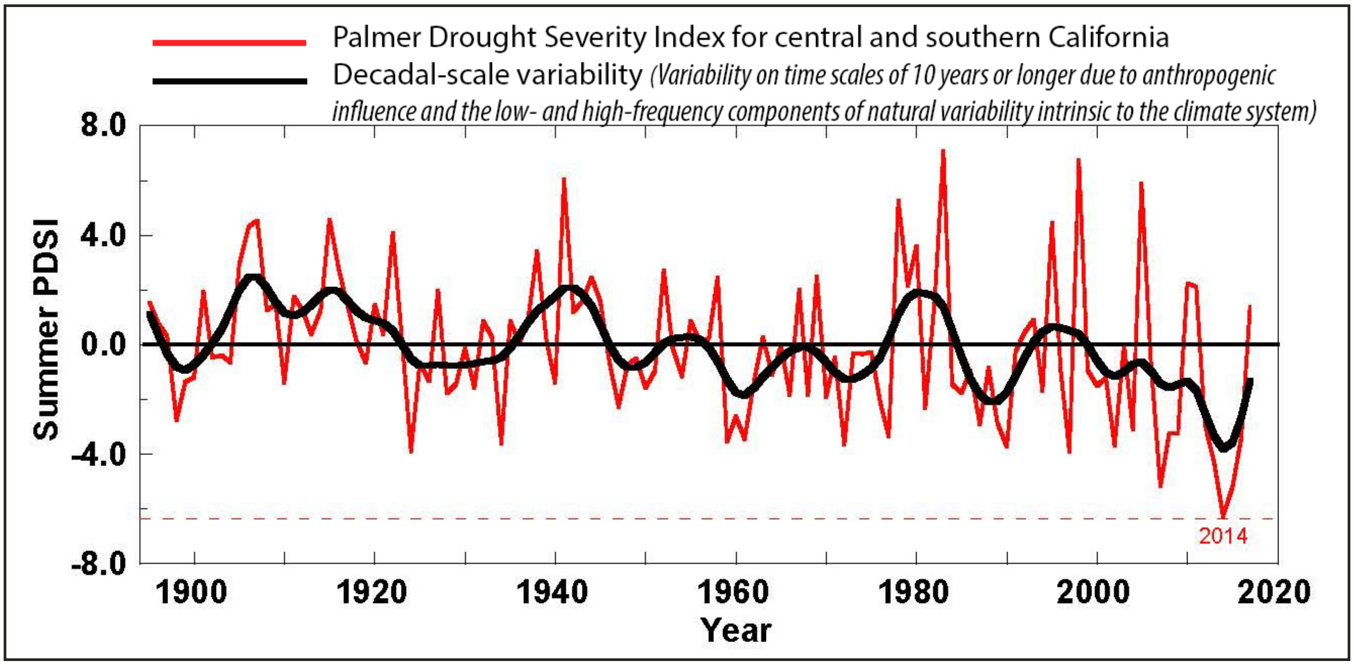
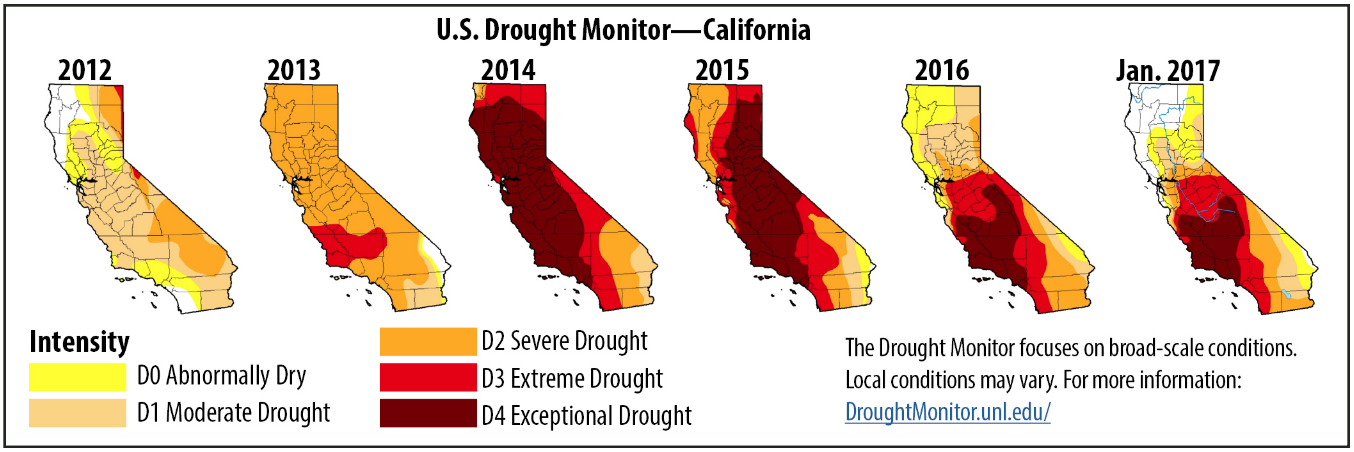


Figure 1 - Summer Palmer Drought Severity Index (PDSI) values for central and southern California.The lowest value for the 1895-2017 period occurred in 2014. This region includes the counties with the highest levels of tree mortality during the 2012-2017 drought. (Figure modified from Griffin and Anchukaitis 2014, Fig 1a.)

Drought can be measured in many different ways. The ***U.S. Drought Monitor*** uses a number of measurements, including precipitation, snowpack, and streamflow, to identify general drought areas by intensity. According to the Drought Monitor, the 2012–2017 period constituted a drought emergency (California Department of Water Resources, U.S. Drought Monitor). In 2014–2015, over half the state experienced an Exceptional Drought severity classification. The Drought Monitor maps (Figure 2) show the increasing severity of drought in California from 2012–2015, with a gradual lessening in 2016– 2017.


U.S. Drought Monitor—California

The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. For more information: DroughtMonitor.unl.edu/

Figure 2 - The U.S. Drought Monitor maps of 2012 through early January 2017 illustrate the severity of drought. Maps from 2012-2016 are presented from the last report date in September noting the closest date to end of water year. D1 is the least intense drought level and D4 the most intense; D0 areas are not in drought. A full description of each drought severity classification is available from the U.S. Drought Monitor website.

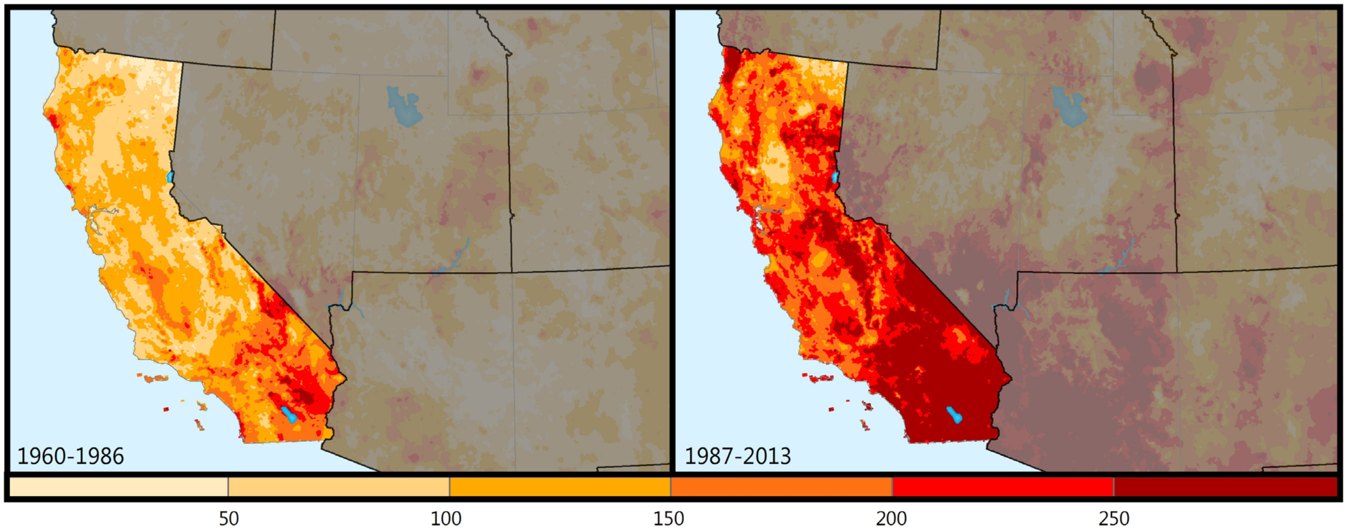


Figure 3 - Drought spatial variability in California. These Cumulative Drought Severity Index maps compare intensity and frequency of drought over two 27-year time periods. The maps show that droughts in many areas of the state became more severe. Visit the U.S. Forest Service Drought Gallery for 100-year datasets and additional maps specific to other resource areas (e.g., rangelands). (Click on the map for an interactive version.)

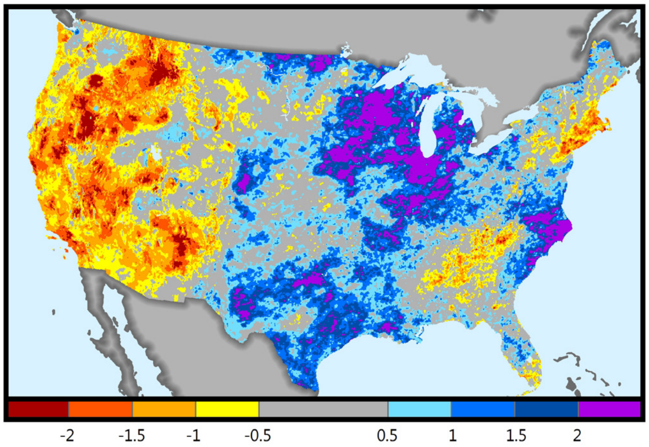


Figure 4 - The interactive Moisture Deficit and Surplus 2000-2016 map shows the changes in soil moisture in 3-year windows. These time periods show moisture patterns that can contribute to drought in some areas but flooding in others.

Intensity of droughts varies (Figures 3 and 4), and drought as an independent stressor depleting ecosystem water balance can have damaging environmental impacts (Clark et al. 2016).

Drought also interacts with ecosystem processes and functions, and can exacerbate the effects of other stressors and disturbances on primary productivity and survival, such as increased insect outbreaks and wildfire, resulting in more profound ecological, economic, and social outcomes (Clark et al. 2016, Thorne et al. 2016).

Climate change projections for California show an expected temperature increase of 4.7–10.5 degrees Fahrenheit by the end of the century, leading to reduced snowpack and earlier seasonal snowmelt. The temperature increase could potentially lead to decreased water quantity and quality (due to increased erosion and sedimentation) and increased risk of wildfire frequency and intensity (Cook et al. 2015).

Climate change is also expected to result in increased seasonal weather variability and a possible increase in the frequency and intensity of droughts in the future (Gregory et al. 1997, Cook et al. 2015, Diffenbaugh et al. 2015). This is similar to the pattern shown in the last three decades in Figure 1.

California already has a relatively high degree of precipitation variability when compared to the rest of the continental U.S. (Dettinger et al. 2011) (Figure 5). Higher winter and summer temperatures will further exacerbate the situation by reducing California's snowpack by 48–65 percent (Walton et al. 2016) (Figure 6).

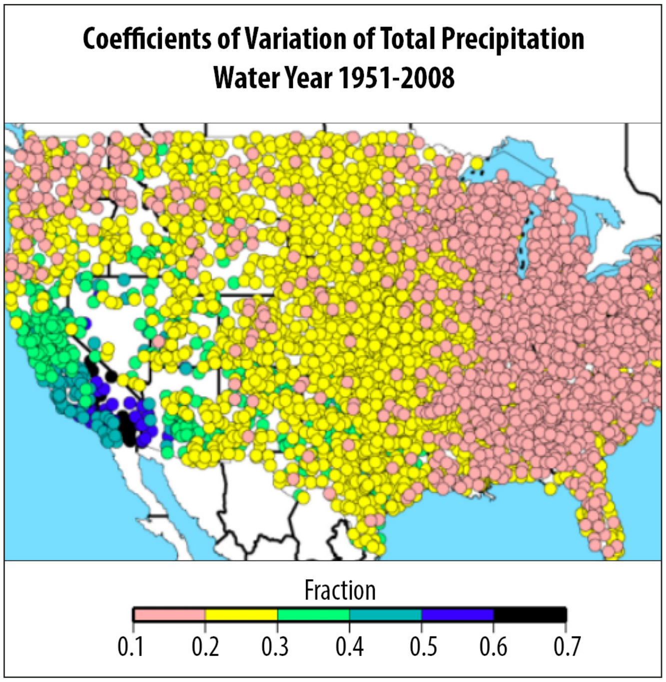
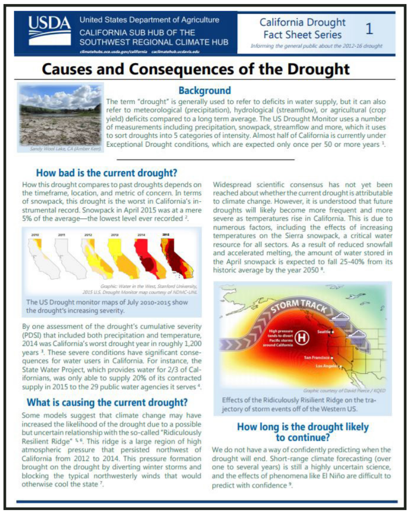


Figure 5 - Precipitation in California is highly variable from year to year as illustrated by the standard deviation/mean coefficients of water year precipitation totals (October–September) from 1951-2008 from sites across the U.S. (Dettinger et al. 2011). In this figure, "coefficients of variation" refers to the extent of variability in relation to the average annual precipitation of each plotted location.

Increased evaporative demand and low soil moisture can promote water stress and weaken trees (Fried et al. 2004). Warmer weather can increase wildfire frequency, compounding the future risk to forests from drought. In addition, human population growth is likely to exacerbate these concerns due to greater demands for natural resources and an expanding wildland-urban interface (California Climate Change Assessments 2006).

Additional information on the ecological context of droughts in California can be found in the [USDA California Climate Hub Drought Fact Sheet](#) series.



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California Drought Fact Sheet Series 1
Informing the general public about the 2012-16 drought

Causes and Consequences of the Drought

Sandy Wool Lake, CA (Amber Kerr).

Background

The term "drought" is generally used to refer to deficits in water supply, but it can also refer to meteorological (precipitation), hydrological (streamflow), or agricultural (crop yield) deficits compared to a long term average. The US Drought Monitor uses a number of measurements including precipitation, snowpack, streamflow and more, which it uses to sort droughts into 5 categories of intensity. Almost half of California is currently under Exceptional Drought conditions, which are expected only once per 50 or more years [1].

How bad is the current drought?

How this drought compares to past droughts depends on the timeframe, location, and metric of concern. In terms of snowpack, this drought is the worst in California's instrumental record. Snowpack in April 2015 was at a mere 5% of the average—the lowest level ever recorded [2].

Graphic: Water in the West, Stanford University, 2015 U.S. Drought Monitor map courtesy of NDMC-UNL

The US Drought monitor maps of July 2010-2015 show the drought's increasing severity.

By one assessment of the drought's cumulative severity (PDSI) that included both precipitation and temperature, 2014 was California's worst drought year in roughly 1,200 years [3]. These severe conditions have significant consequences for water users in California. For instance, the State Water Project, which provides water for 2/3 of Californians, was only able to supply 20% of its contracted supply in 2015 to the 29 public water agencies it serves [4].

What is causing the current drought?

Some models suggest that climate change may have increased the likelihood of the drought due to a possible but uncertain relationship with the so-called "Ridiculously Resilient Ridge" [5,6]. This ridge is a large region of high atmospheric pressure that persisted northwest of California from 2012 to 2014. This pressure formation brought on the drought by diverting winter storms and blocking the typical northwesterly winds that would otherwise cool the state [7].

Widespread scientific consensus has not yet been reached about whether the current drought is attributable to climate change. However, it is understood that future droughts will likely become more frequent and more severe as temperatures rise in California. This is due to numerous factors, including the effects of increasing temperatures on the Sierra snowpack, a critical water resource for all sectors. As a result of reduced snowfall and accelerated melting, the amount of water stored in the April snowpack is expected to fall 25-40% from its historic average by the year 2050 [8].

Graphic courtesy of David Pierce / KQED

Effects of the Ridiculously Risilient Ridge on the trajectory of storm events off of the Western US.

How long is the drought likely to continue?

We do not have a way of confidently predicting when the drought will end. Short-range climate forecasting (over one to several years) is still a highly uncertain science, and the effects of phenomena like El Niño are difficult to predict with confidence [9].

Figure 6 - The Drought Fact Sheet series provides information on the varied effects of drought and its related stressors on [Forests](#), [Rangelands](#), and [Croplands](#).

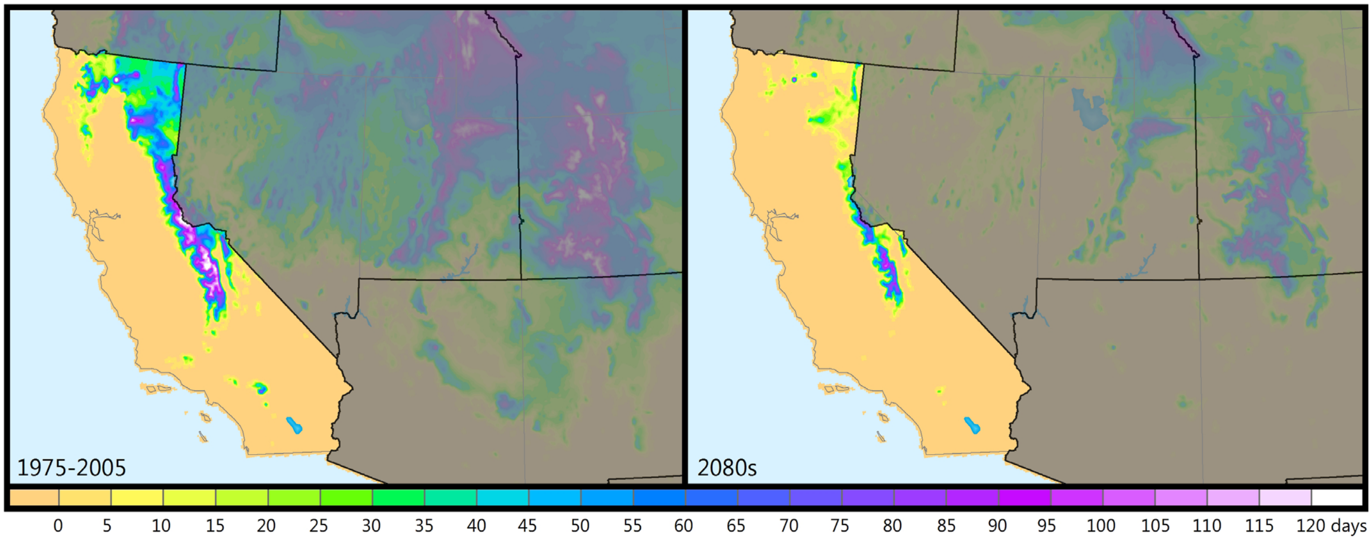

Figure 7 - Historical and projected snow residence times in days in California. The maps compare compare the average length of time that snow remains before melting (in days) between 1975 and 2005 versus a projected map of 2080. (Click on map for interactive version and for additional maps depicting Snow Water Equivalent.)

Response to Drought in California—Organization, Capacity Building, and Policy

State of California

With California facing water shortfalls in the driest year in recorded state history, Governor Edmund G. Brown Jr. proclaimed a State of Emergency on January 17, 2014, and directed state officials to take all necessary actions to prepare for these drought conditions.[1]

Following this proclamation, Proposition 1, California's $7.5 billion water bond, was approved overwhelmingly by voters in November 2014. This water bond is a significant statewide investment in water supply infrastructure, including ecosystem and watershed protection and restoration projects.

Governor Brown signed additional emergency legislation in March 2015 that provided more than $1 billion in additional funding for drought relief and critical water infrastructure projects. In addition, the Governor issued an executive order on April 1, 2015, which directed the first ever statewide mandatory water reductions. The order announced actions to save water, increase enforcement to prevent wasteful water use, streamline the state's drought response, and invest in new technologies to make California more drought resilient.

A full summary of all state-issued drought declarations is available on the State of California Department of Water Resources website.

The California Water Action Plan (last updated in January 2016) is the state's official water policy. The purpose of the plan is to lay out the actions that must be taken to protect water supplies for people and the environment, and to address the state's critical water resource problems. The ***California Water Action Plan*** details 10 actions to address these challenges and deliver a more reliable water supply.

Implementing the ***California Water Action Plan*** requires agency cooperation and commitment to achieving all 10 of the actions through 2019. The U.S. Forest Service, Pacific Southwest Region, has been a key partner in helping the state reach its ***Water Action Plan goals***, many of which have direct implications for the ecosystem integrity of National Forest System lands.

Pacific Southwest Region Drought Task Force

In support of the state's continuing drought conditions, the Pacific Southwest Region chartered an internal ***Drought Task Force*** in May 2014. This task force, comprised of both U.S. Forest Service leadership and program managers, provides guidance to resource areas and programs impacted by the drought. The task force also coordinates with other federal and state agencies (e.g., USDA Natural Resources Conservation Service, National Oceanic and Atmospheric Administration, the State Water Board, and California Natural Resources Agency).

The Pacific Southwest Region developed a ***Leadership Intent on Drought and Water Conservation***:

> **"Our response to this critical situation must demonstrate our commitment as conservation leaders, and must align with our two foundational focus areas: *Ecological Restoration* and *Healthy Workplace and Workforce.* As a conservation agency, the Forest Service has a responsibility to serve as a model for the wise use of limited resources such as water."**

The task force developed a Drought Web Portal and a Drought Response Toolbox that contain additional guidance for managing the drought.

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[1] On April 7, 2017, Governor Brown issued an executive order ending the drought state of emergency in all California counties except Fresno, Kings, Tulare, and Tuolumne, where emergency drinking water projects will continue to help address diminished groundwater supplies.

Tree Mortality—One of the Most Significant Consequences of Drought in California

Forests in California are highly prone to large scale wildfires and bark beetle outbreaks. The combined effects of decades of fire suppression, historic logging and management practices, greatly increased forest stand density (i.e., the number of trees per unit area) and drought. When there are more trees on the landscape than can be supported by the resources available (e.g., water, light, nutrients), trees have to compete for available resources and can become stressed. Stress weakens trees, leading to increased susceptibly to insects such as bark beetles (Clark et al. 2016).

In California, drought is the "trigger" for increased bark beetle activity. The longer and more extreme the drought, the higher the likelihood of large scale, beetle-mediated tree mortality. Trees rely on pitch production to resist bark beetle attacks. When water-stressed, a tree's ability to produce pitch is diminished, and bark beetles are able to successfully attack and kill weakened trees (Hart et al. 2015).

Recent tree mortality in California has had ecological and economic effects across both public and private lands (Figure 8). Over 129 million trees on 8.9 million acres have died since 2010, with the southern Sierra Nevada being the most heavily impacted region. Worth noting is the proportional decrease in mortality at the conclusion of the multi-year drought, with 27 million dead trees observed in 2017 compared to 62 million in 2016 (U.S. Forest Service Tree Mortality).

Figure 8 - Tree mortality across the Musick Creek and Bald Mountain landscapes on the Sierra National Forest, High Sierra Ranger District (photo courtesy of Jim McDougald, CAL FIRE).

Response to Tree Mortality in California

Governor Brown's state of emergency declaration encompassed the southern Sierra in 2015 and prompted the Office of Emergency Services and CAL FIRE to establish a *Tree Mortality Task Force* comprised of state and federal agencies, local governments, and utilities, to coordinate actions and monitor conditions. In conjunction with the Governor's declaration, the Regional Forester in the Pacific Southwest Region made tree mortality response a top priority for the region by establishing a *Regional Tree Mortality Response Team* consisting of representatives from the National Forest System, State and Private Forestry, and Research and Development Deputy Areas. This Team was initially tasked with coordinating response efforts across the three forests that were at the epicenter of the tree mortality situation: the Stanislaus, Sierra, and Sequoia national forests. With the elevated mortality increasing, the Eldorado, Tahoe, and Lake Tahoe Basin are now part of the Response Team's area.

The U.S. Forest Service is coordinating its response with multiple agencies and cooperators in addition to the Governor's Task Force. The current focus is on reducing risks and prioritizing efforts in areas where dead and dying trees pose the greatest risk to life and property. This includes areas near communities in the wildland-urban interface, communication infrastructure, and high use recreation sites, as well as along transportation routes and adjacent to utility corridors. Hundreds of thousands of trees have been felled and removed in these areas.

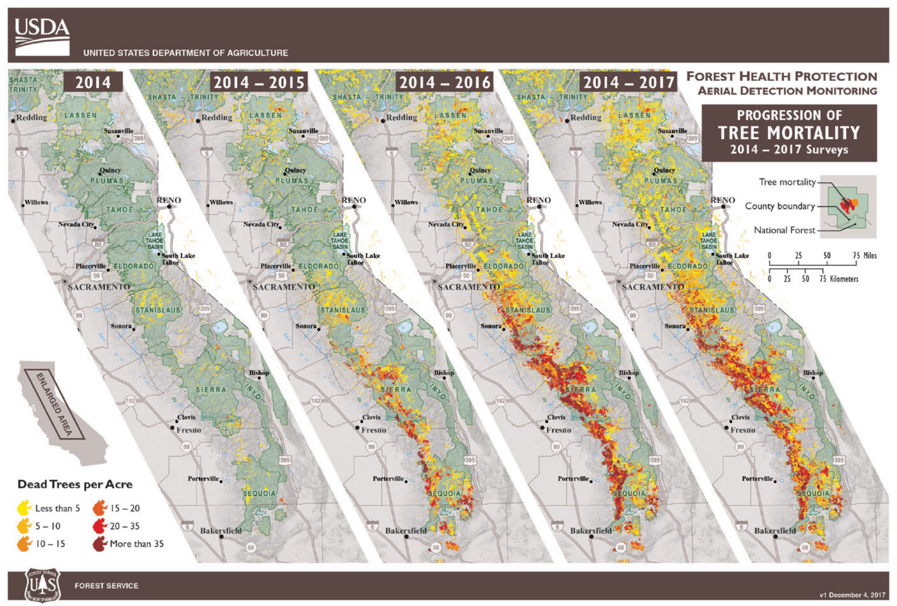

Figure 9 - Progression of Tree Mortality (2014-2017 U.S. Forest Service Region 5 Aerial Detection Program Surveys). Additional illustrations spanning 2012-2016 are available via CAL FIRE's ***Tree Mortality Viewer.***

The Future of California's Forests

Increasing temperatures and moisture stress may cause changes in the distribution and abundance of tree species in some areas (Thorne et al. 2016, Thorne et al. 2017). For example, some California forests may shift from dominance by conifers to hardwoods (Shaw et al. 2010). These effects are expected to intensify in the coming decades, via direct (temperature, precipitation) and indirect (fire, insects) stressors and disturbance (Thorne et al. 2017).

Climate change will require forest management that allows resource managers to experiment with adaptation strategies. Because these effects do not recognize ownership or management boundaries, collaboration will be required among private landowners, government, and stakeholders to build resilience in forest ecosystems at large spatial scales.

The Forest Service recognizes the need for a science-based approach to managing the large-scale impacts of tree mortality. With the help of the public, partners, scientists, and resource specialists, the agency is developing a restoration framework that identifies priority locations where treatments will be implemented over the next decade to address this challenge.

Science and Management Symposium—Lessons Learned from Extreme Drought and Tree Mortality in the Sierra Nevada: How Can Past Events Inform Our Approach Forward?

Symposium Overview

The U.S. Forest Service, Pacific Southwest Region, and the USDA California Climate Hub co-hosted a two-day symposium in July 2017. Participants in the symposium examined the relative contributions of drought, beetle activity, and past management practices (with a focus on wildland fire management) in influencing patterns of tree mortality across the landscape.

The symposium provided a forum in which experts and managers shared findings, results, and experiences from the tree mortality event to to examine opportunities for the development, planning, and implementation of future forest management strategies and activities.

The first day was structured as a science symposium to examine the state of knowledge concerning tree mortality in the Sierra Nevada, share ongoing work, and identify remaining gaps and questions. The second day focused on a smaller working group that synthesized the information shared during the symposium and outlined management objectives.

A summary of the key points from each of the Day 1 sessions is provided in Table 1. Presentations are posted on the USDA California Climate Hub's website.

Table 1 - Main take-aways and related citations from the Day #1 plenary and break-out sessions. The first three rows (in gray) correspond to symposium sessions focused on a review of past conditions. The last three rows (in green) relate to those sessions that focused on future management opportunities.

Symposion Sessions	
Session	***Key Points***
Considerations of Past Conditions	» Three factors largely contributed to the mortality currently observed on the landscape throughout the Sierra Nevada: 1) due to water stress, a reduced ability of forested ecosystems to support and maintain ecological processes and a diverse community of organisms, 2) warming temperatures, and 3) increased bark beetle activity. » Drought, higher temperatures, ozone, and nitrogen deposition can weaken trees. Reducing stand density may increase water availability for some trees, but this varies by site (e.g., flat versus sloped conditions). Tree death occurs at different rates depending on local environmental conditions. » As space to grow becomes limited, trees change how to allocate the products of photosynthesis. Processes that require photosynthate include maintenance, respiration, fine roots, reproduction, insect/disease resistance. Insect/disease resistance is one of the first to decrease because it requires the tree to invest a significant amount of its resources. » California is one of only a few states where fire historically accounts for more annual mortality than bark beetles. The outcome after beetle infestations largely depends on the initial forest structure (e.g., age class, heterogeneity, soil substrate, moisture conditions, etc.). *Key sources: Grulke et al. 2003a, 2003b, Fettig et al. 2013, McDowell et al. 2011, Safford and Van de Water et al. 2014, Stephens et al. 2015*

Symposion Sessions	
Session	*Key Points*
Patterns and Drivers of Tree Mortality: From Tree to Landscape	» With droughts projected to increase in frequency and severity, tree and crown size will be increasingly important. Larger trees with larger crowns also have deeper roots that can more easily access water. » Mortality occurred in different size classes depending on the tree species. Each type of beetle has its own preferences (e.g., pine bark beetles attack larger trees, whereas cedar bark beetles attack smaller trees). Managers must consider tree species/size, beetle preferences, and interactions between these to fully understand the biological mechanism behind each case of tree mortality. » As the climate changes, we may begin to observe new and unanticipated threats leading to novel interactions. Patterns of mortality that are observed after drought and beetle activity are not necessarily identical to those observed after fire. » At large spatial scales, fire events are driven more by weather and topography than by beetle-induced mortality. At a stand level, the reverse may be true. » Hazard tree removal, increased forest thinning, increased prescribed fire, and an increased tolerance for allowing some wildland fires to burn without intervention (if conditions allow) are all management options. However, funding, burn windows, and current incentives/lack of markets serve as barriers to implementation of these options. *Key sources: Coop et al. 2016, Hart et al. 2015, Littell et al. 2016*
Moving Forward with Changed Conditions: The Future of California Forests with Climate Change and Extreme Events	» We are beginning to observe human-influenced ecosystems that lack natural analogs, and we need to determine how we value these systems. Vulnerability assessments can help identify management priorities. New ways of management and collaboration may be necessary to address the scale of the issues. Increasing the pace and scale of forest treatments and managed fire on the ground remain a priority. » Identified inefficiencies in process and use of resources (e.g., time-intensive environmental analysis and decision-making, and compartmentalized budgeting) should be addressed. We should revisit our best management practices in addition to targets. » Landscapes are changing faster than our government institutions; institutions need to be nimble, rewarding risk takers as appropriate. Streamlining contracting and using tools and authorities that improve effectiveness and efficiency (e.g., the Good Neighbor Authority and the Wyden Amendment) will be increasingly important in the future . *Key sources: Allen et al. 2010, Hurteau et al. 2014, Kershner et al. 2014, North et al. 2009; North et al. 2014*

Sessions Focused on Future Management Opportunities

Panel Discussion	*Key Points*
Expert Station: Reforestation	» Growing and retaining large trees remains a goal for forest management, but density and spatial arrangement, and facilitation of heterogeneity, need to be considered for stand management concerns. There is interest in continuing to examine different options for forest structure that lead to the greatest degree of resilience in forested ecosystems. » There is interest is understanding how best to approach reforestation, and forest and vegetation management in the areas most impacted by tree mortality. This includes a re-examination of the current seed zone map for the state, and considerations of future climate conditions as compared to the natural range of variation of current and historic vegetation composition. » Genetics and seed stock sources are likely to play an increasingly important role in reforestation efforts. Managers must consider which species and genotypes to plant in which locations in the face of climatic conditions.
Expert Station: Fire and Fuels	» It is important to consider the social factors that limit the implementation of fuel treatments, including prescribed fire. Funding is not always the limiting factor. Many parts of California have high population density adjacent to forested areas, in addition to strict air quality standards. These present obstacles to using fire as a management tool. We must make more strategic decisions about when and how to burn. » We need to build social acceptance of burning/smoke and help the public understand the tradeoff of smoke produced under controlled versus wildfire conditions. We also need to carefully consider where we are not going to conduct treatments and which parts of the landscape we will not actively manage. » Opportunities to improve management of fire and fuels include: implementation of the Fire Memorandum of Understanding; continuing to build strong CAL FIRE and U.S. Forest Service partnerships; building public trust through prescribed fire on public land brokered through CAL FIRE; developing more markets for underutilized woody material; and conducting more research on the ecological effects of wildfire management.
Expert Station: Partnerships and Opportunities	» There is a lack of capacity to implement the projects that are needed on the ground to improve forest resilience to drought, wildfire, and interacting climate stressors. New partnerships (e.g., conservation finance firms) are needed to provide additional capacity and resources. » Although partnerships can take many forms, successful collaboratives and partnerships will establish goals and objectives early and clearly communicate timeframes for planning and action. » Starting small and scaling up efforts to larger plans and projects are important for building trust among emerging partners and stakeholders.

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Visit the U.S. Forest Service Drought Gallery for additional maps, apps, and resources.

App: Drought Over Time

Web Mapping Application by USFSMapsandApps. Last Modified 7/7/17

The maps shown here compare intensity and frequency of drough
periods.

App: Forest Service Response to Drought 2012-2016

Web Mapping Application by USFSMapsandApps. Last Modified 7/26/1

The Forest Service Response to Drought Map shows areas where
accomplished stand density reduction activities within areas of sus
droughts between 2012 and 2016.

http://arcg.is/2uTALWW

Cover photo - Dead trees along mountain road in the Sequoia National Forest, May 2016 (U.S. Forest Service)
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