A summary of current trends and probable future trends in climate and climate-driven processes in the Los Padres National Forest and neighboring lands

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INTRODUCTION

This summary of climate and climate driven trends in southern California is a product of the Forest Service's Pacific Southwest Region Ecology Program. This document synthesizes and summarizes current trends and projected future trends related to climate change on the Los Padres National Forests and surrounding lands in southern and central California. This analysis is primarily based on local weather station data and published literature; in some instances, important and credible findings from unpublished studies are also included. The summary begins with local and regional trends in temperature and precipitation, then examines how these trends are affecting hydrology, fire, vegetation and wildlife in the study area. A summary of projected future trends in climate and climate affected resources is also provided. This document offers information of fundamental importance for National Forest management and planning in the face of global change. This summary is a living document and will be updated regularly.

I. Local trends in climate over the past century

The temperature and precipitation data presented in this section are derived from six Cooperative Observer Network (COOP) stations in the vicinity of the Los Padres National Forest (LPNF) (WRCC, 2015). COOP stations were selected based on their proximity to the LPNF and the length and completeness of

Station	Elev. (Feet)	Latitude	Longitude	Proximity to National Forest	Data Range	Years of Excluded Data (Temp/Ppt)
Monterey	385	36.59028	-121.91028	13.75 N of LPF	1906-2015	46/39
Cal Poly, SLO	308	35.30556	-120.66194	2 mi W of LPF	1928-2015	4/55
Lake Cachuma	795	34.58222	-199.98167	1 mi N of LPF	1953-2015	2/7
Santa Barbara	5	34.416677	-119.68444	3 mi S of LPF	1893-2015	9/40
Ojai	745	34.44778	-119.2275	1 mi S of LPF	1906-2015	3/18
Sandberg	4510	34.74361	-118.72417	5 mi E of LPF	1948-2015	0/10

Table 1. Weather station summary information. Data obtained from US COOP maps http://wrcc.dri.edu/coopmap/#

their records. Table 1 summarizes the locale and data extent for the selected weather stations. Weather records were evaluated for trends in the mean minimum, mean and mean maximum annual temperatures, as well as mean annual precipitation, inter-annual variability in precipitation and mean annual snowfall. Our analysis is supplemented with historic trends in temperature and precipitation derived using spatial data from the PRISM climate dataset (Daly et al., 1994) and compiled by Rapacciuolo et al. (2014) (Figure 1 & 2).

TEMPERATURE

California is currently (2012-2014) experiencing the hottest and driest period in its recorded climate history (time since 1895) (Mann and Gleick, 2015). The magnitude and direction of temperature change is variable across the state and depend on the time series and scale of the analysis in question. For example, there was an order of magnitude increase in warming between 1970-2006 when compared to 1918-2006, indicating accelerated warming in the last 35 years in California (Cordero et al., 2011). A recent summary of these trends is presented in Rapacciuolo et al. (2014) and broken down by ecoregion. The authors report an average statewide temperature increase of 0.81° F between historic (1900-1939) and modern (1970-2009) times, with coastal southern California experiencing one of the largest (next to the southern Desert regions) increases in mean (1.26° F), min (1.89° F) and max (0.58° F) temperature. Although not as pronounced as southern California, the central coast ecoregion, which includes the Monterey ranger district, shows an increase in mean (0.76° F) and minimum (0.99° F) temperature and a decrease in maximum (-0.74° F) temperature over this same time period (Rapacciuolo et al., 2014).

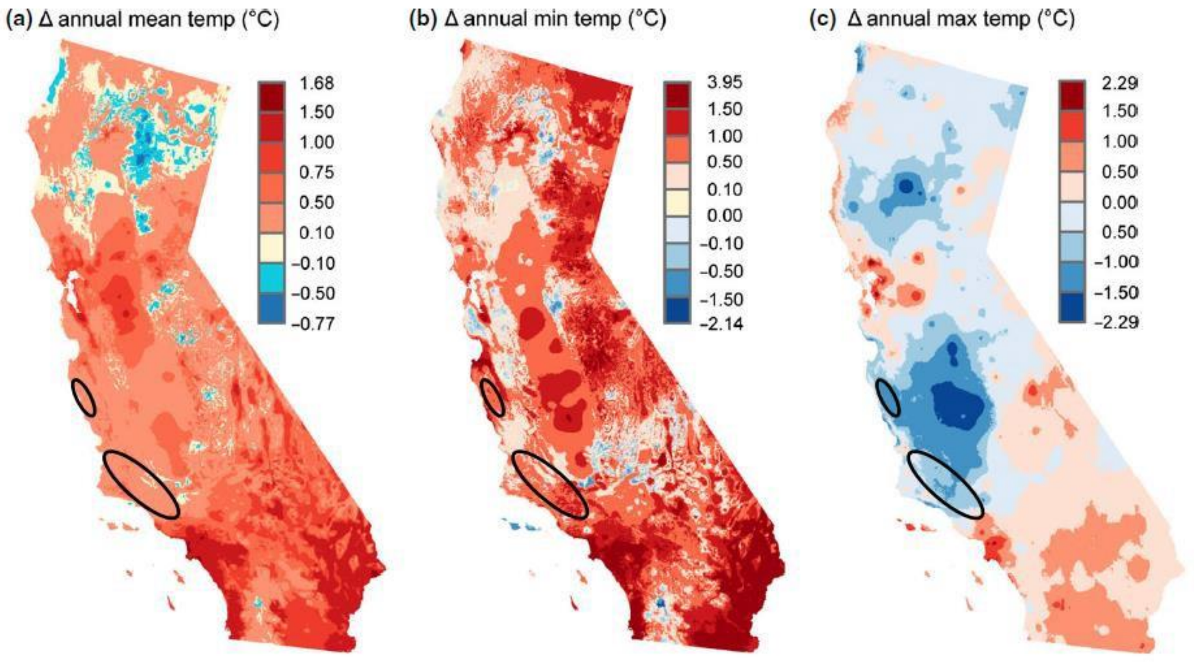

Figure 1. Spatial representation of differences in A) annual mean, B) annual minimum and C) annual maximum temperature (°C) between historic (1900-1930) and modern times (1970-2009). Black circles represent the vicinity of the LPNF. Figures from Rapacciuolo et al. 2014.

	Monterey	Cal Poly, SLO	Lake Cachuma	Santa Barbara	Ojai	Sandberg
Elevation (ft.)	385	308	783	5	745	4510
Temperature						
Max (F°)	**-1.5***	**+2.3*****	**+3.7*****	NS	NS	**+3.5*****
Mean (F°)	NS	**+1.4****	**+2.4*****	**+2.7*****	**+1.1****	**+3.6*****
Min (F°)	**+2.4*****	NS	NS	**+4.5*****	**+2.7*****	**+3.8*****
Freezing (mo/yr)	-	-	-	-	NS	**-1.2*****
Precipitation						
Total (in.)	NS	NS	NS	NS	NS	NS
CV	NS	NS	NS	NS	**+0.3*****	NS
Snowfall (in.)	-	-	-	-	-	**-41.0*****

Table 2. Direction, magnitude and statistical significance of climatic shifts at six weather stations in close proximity to the LPNF. Numerical values indicate the difference between the expected values (derived from the regression equations) for the earliest and most recent years of available climate data. - = not significant, * $P<0.05$, **$P<0.01$, ***$P<0.001$. 'NA' indicates locations and climate parameters where there was insufficient data to conduct a statistical analysis.

These patterns are consistent with the temperature data obtained from the six weather stations in close proximity to the LPNF. All stations show statistically significant increases in at least one of the temperature parameters (mean minimum, mean annual and mean maximum; Table 2, Figure 3). For four of the six stations, temperature increases were greatest in mean minimum (nighttime) temperature when compared to mean and mean maximum (daytime) temperatures, a finding consistent across California (Cordero et al., 2011; LaDochy et al., 2007) and the globe (Vose et al., 2005). The most urban weather station in downtown Santa Barbara had the largest increase in mean minimum temperature. A similar finding in the Los Angeles Basin is largely attributed to urban heat generation and retention from human created surfaces (e.g. concrete and asphalt) (LaDochy et al., 2007). There was a cooling trend for mean maximum temperature in Monterey, which is consistent with findings across the central coast ecoregion (Rapacciuolo et al., 2014).

PRECIPITATION

Since 2012, California has experienced a record setting drought that includes the lowest yearly precipitation on record (Diffenbaugh et al., 2015). Tree ring data suggests that the 2012-2014 drought is the most severe in the past 1,200 years (Griffin and Anchukaitis, 2014). While the precipitation deficits beginning in 2012 are not unprecedented in the paleoclimate, when coupled with rising temperatures, the current drought stands out as the most severe since the 9th century (Griffin and Anchukaitis, 2014). Despite the current drought conditions and long-term declines in precipitation in southern California indicated by Rapacciuolo et al. (2014) (Figure 2), there were no significant drying trends identified from the five weather stations across the southern parts of the LPNF (Table 2). Despite the lack of significant trends in precipitation at these weather stations, drier ecosystem conditions are still occurring due to rising temperatures and increased evapotranspiration (Dai et al., 2004; Diffenbaugh et al., 2015). Reduced precipitation may also be more prevalent in highly populated areas where urban air pollution (i.e., high levels of GHG and CO_2) can contribute to rainfall suppression in California (Givati and Rosenfeld, 2004). Climate analyses indicate that the western central coast region (encompassing northern Santa Barbara to Monterey county) has experienced increased rainfall over the past century with a 5% increase (28.2mm) between the time periods 1951-1980 and 1981-2010 (Flint et al., 2013), however this was not detected in our analysis of Monterey precipitation records (Table 2).

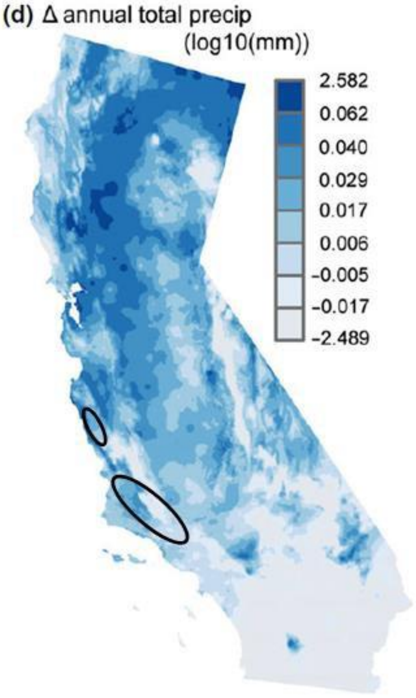

Figure 2. Spatial representation of difference in total annual precipitation between historic (1900-1930) and modern times (1970-2009). Figures from Rapacciuolo et al., 2014.

The Ojai weather station shows increases in interannual variation in precipitation through time. Even if mean annual precipitation is not changing, increases in interannual variability, which is already very high in California, has important implications for ecosystems and fire management. Southern California has the most variable rainfall regime of the world's Mediterranean climate zones, and has more intense summer drought compared to other Mediterranean sites, with < 5% of precipitation occurring in the summer months (Cowling et al., 2005). Over the last 40 years, there have been significant increases in the length of time between rainfall events in the warm season (Groisman and Knight, 2008), thereby creating longer drought periods in California.

General trends in snowfall and snow pack have been noted across the western United States since the mid-1900's, including less snowfall (Knowles et al., 2006) and decreased snow depth (particularly at lower elevation sites; (Barnett et al., 2008; Grundstein and Mote, 2010; Mote et al., 2005). Belmecheri et al. (2015) used tree ring data to estimate that current (April 2015) snow water equivalents in the Sierra Nevada are at a 500 year low. While most of the weather stations in close proximity to the LPNF do not receive snow, there was a significant declining trend in annual snowfall amounts at Sandberg, the only weather station with snow data (Table 2).

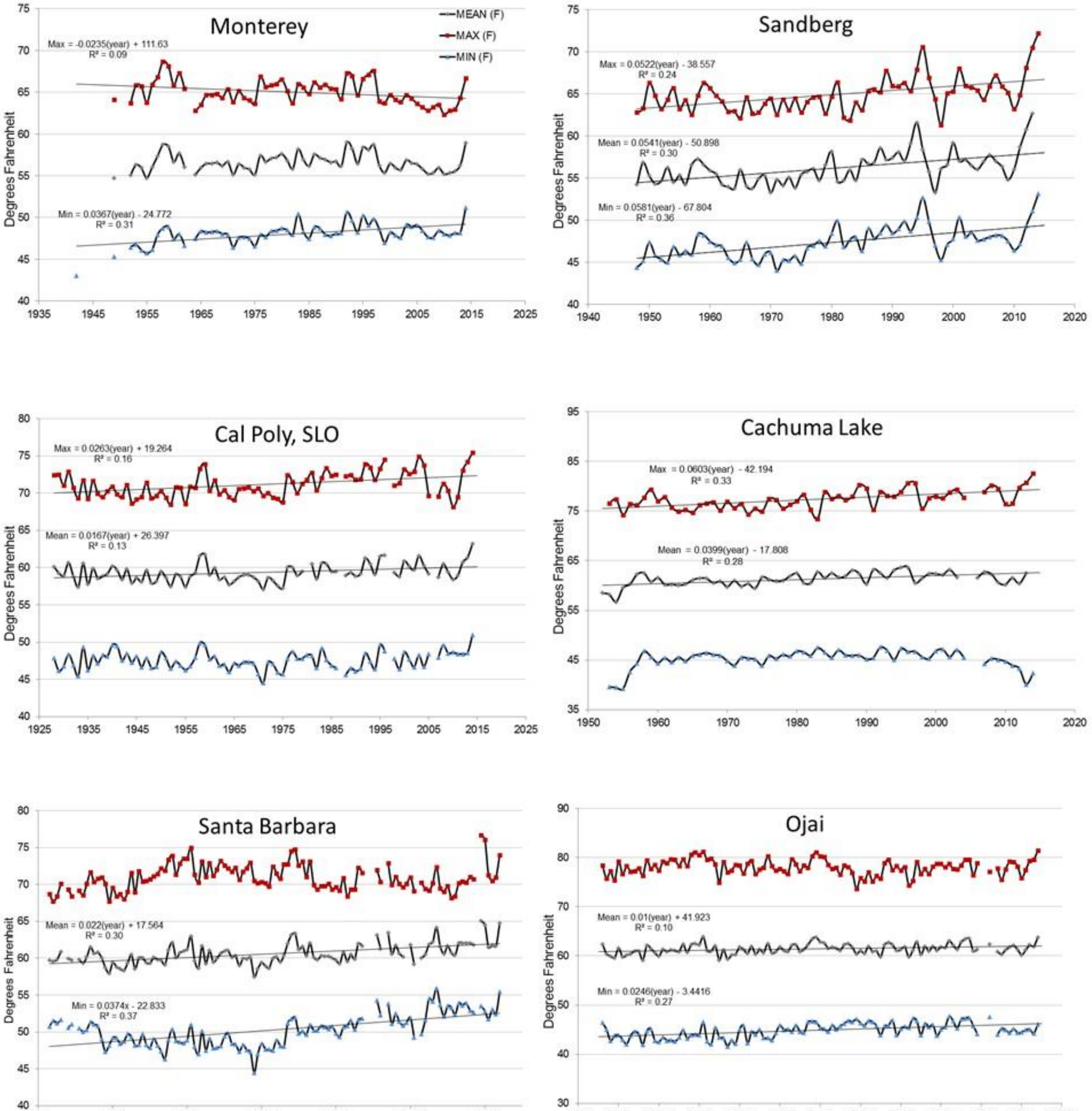

Figure 3. Annual mean maximum ( ), mean ( ) and mean minimum ( ) temperatures at six weather stations in close proximity to the LPNF. Linear regression equations, R^2 and trend lines are only shown for statistically significant (P<0.05) regressions.

HYDROLOGY

Across the western United States, widespread changes in surface hydrology have been observed since the mid-1900s. These shifts include: earlier snow melt and spring runoff (by 0.3 to 1.7 days per decade; (Barnett et al., 2008; Hamlet et al., 2007; Maurer et al., 2007; Stewart et al., 2005), decline in total spring runoff (Moser et al. 2009), rising river temperatures (Kaushal et al., 2010), and increased variability in streamflow (Pagano and Garen, 2005). Moser et al. (2009) found that over the past 100 years, the fraction of annual runoff that occurs during April–July has decreased by 23% in the Sacramento River basin and by 19% in the San Joaquin River basin in California. During this same time snow pack accumulation has decreased (Mote et al., 2005). Knowles et al. 2006 found that shifts in precipitation from rain to snow have occurred since the middle of the last century. There are also downward trends in April 1 snow water equivalent (SWE), especially in warmer coastal areas (Hamlet et al., 2007).

In addition to temporal hydrological shifts, California has exhibited one of the greatest increases in variability in streamflow in the western U.S. since the 1980's (Pagano and Garen, 2005). Forest Service staff and a streamflow tracker managed by The Nature Conservancy (http://www.casalmon.org/disappearing-rivers) have noted that many seasonal and intermittent streams on or near the LPNF are drying earlier and exhibiting previously unseen dry stretches (Table 3). In contrast, urbanized streams across southern California are experiencing higher summer water flows than in the mid-20th century due to leaking pipelines, wastewater discharge and runoff from irrigation (Townsend-Small et al., 2013). This increased variability in high and low flows, coupled with high year-to-year persistence (i.e. the probability that a wet year is followed by another wet year or a dry year by a dry year), has resulted in extended and extreme dry and wet spells that are particularly challenging for management of urban infrastructure and other services (Pagano and Garen, 2005).

	Closest ranger district to gauge	**Current compared to historical flow**	**# of historical measurements**	**Category**
Big Sur River	Monterey	< 86.3%	65	Below Normal
Lopez Creek	Santa Lucia	<15.3%	48	Above Normal
Sisquoc River	Santa Lucia	<94.7%	63	Much Below Normal
Santa Ynez	Santa Barbara	<1.4%	60	Much Above Normal
San Jose Creek	Santa Barbara	<91.8	73	Much Below Normal
Santa Paula Creek	Ojai	<77.5%	85	Below Normal
Sespe Creek	Ojai	<78.3%	62	Below Normal Much
Piru Creek	Ojai	<96.3%	42	Below Normal

Table 3. Streamflow data obtained from USGS Waterwatch (http://waterwatch.usgs.gov) and compiled by The Nature Conservancy (http://www.casalmon.org/disappearing-rivers). Weekly average flows are compared to historical values for the same week of the year to determine if streamflow is normal, above normal, below normal, etc. Data above represent streamflow data for September 2015.

Due to the combination of erosive, variable terrain and the position of the coast and transverse mountain ranges in relationship to the coast, much of central and southern California are vulnerable to floods and debris flows after intense precipitation events, especially in areas with recent or recurrent fires (Gabet and Dunne, 2003). Water and sediment flow in southern California has a history of dramatic fluctuations that have been largely driven by multi-decadal climate variability and the El Nino/Southern Oscillation (ENSO) events (Inman and Jenkins, 1999). For example, the sediment carried by the Santa Clara and Ventura Rivers during a single flood year (1969) was greater than the total transported by those rivers during the preceding 25-year period (Inman and Jenkins, 1999). Additionally, rainfall was enhanced throughout southern California between 1950 to 1982 during the intensification of the subtropical westerly jet in response to ENSO (Schonher and Nicholson, 1989). Highly episodic sediment flow, as seen in southern California, can lead to erosion, property damage, loss of life, and destruction of riparian habitats (Gabet and Dunne, 2003). Combined with climate change effects of increased water temperatures, decreased dissolved oxygen levels, and increased toxicity of pollutants (Ficke et al., 2007), increases in turbidity or suspended solids due to erosion are likely to negatively affect aquatic organisms.

FIRE

Low and middle elevation shrublands

Chaparral vegetation constitutes more than a third of the lands administered by the four southern California National Forests (Fried et al., 2004), and shrublands, most of which are dominated by chaparral, constitute approximately 70% (1.4 million acres) of the LPNF. The frequency of fires in low to mid elevation chaparral ecosystems has increased over the last few decades, due to increased human ignitions and increased climate variability (Piñol et al., 1998; Riera et al., 2007). Mean historic fire return interval in chaparral in lowland California was estimated by Van de Water and Safford (2011) to be about 55 years, ranging from 30-90 years (represents pre- Euro-American settlement; see also (Barro and Conard, 1991; Keeley and Fotheringham, 2001; Lombardo et al., 2009). In southern California, many areas dominated by chaparral are burning more often now than they did before Euro-American settlement (Safford and Van de Water, 2014), and modern fire return intervals may now be 10-20 years or less (Safford, 2007).

While historical fire size is debated, it appears that fire size and severity has also recently been growing in southern California. In bigcone Douglas-fir stands of the Los Padres National Forest, Lombardo et al. (2009) identified a shift to more severe fires after the late nineteenth century and also noted a shift to widespread, landscape-scale fires compared to previous mixtures of relatively large and small fires. Minnich (2001) suggested that suppression has created homogenous chaparral fuelbeds which have enabled the growth of unprecedented large-scale fires, but the evidence indicates that large fires were not historically atypical in chaparral fuels (Keeley and Zedler, 2009; Mensing et al., 1999), and fire suppression has had little effect on fire frequency in most of low- and middle-elevations in southern California (Safford, 2007). Others emphasize the role that drought and foehn (Santa Ana) wind events play in fire size (Keeley, 2004; Keeley and Zedler, 2009; Moritz et al., 2004), and attribute increases in the occurrence of large fires since 2000 to drought conditions, which increase dead fuel loading and hence spotting during wind-driven fire events (Keeley et al., 2009). The spread of non-native invasive herbaceous vegetation adjacent to the WUI exacerbates these issues, increasing fire risk due to the presence of readily-available fine fuels. Keeley (2004) found that area burned in chaparral fires in southern California was not closely related to antecedent climate variables, but rather to the occurrence of extreme weather at the time of burning. To understand the effects of climate and weather on fire number and size, Jin et al. (2014) divided wildland fires into two categories; those that are tied to Santa Ana wind events and those that are not. Their work highlights that above average winter precipitation enhances the number of non-Santa Ana wind driven fire events. They also found that the area burned in non Santa Ana fire events have increased through time (1959-2009), yet fires occurring during Santa Ana wind events have not.

Syphard et al. (2007) found that human-related variables like population density and distance to communities were the best predictors of fire frequency in southern California. Exurban, or intermediate density development, as often seen in southern California National Forest WUI zones, is linked to the highest level of ignitions (Syphard et al., 2007). With its dense (637 people per mi^2) and growing (11% between 1990 and 2000) human population densities, southern California is at particular risk for increasing fire frequencies at lower elevation sites (Underwood et al., 2009).

Middle and high elevation conifer forests

The high frequency of fires at lower elevations in the southern California foothills is not seen in the southern California mountains, leading to different fire patterns at these higher elevation sites over the past century. Mixed conifer forests in the Transverse and Peninsular ranges in southern California experienced frequent fires prior to the 20th century (Skinner et al., 2006), but contrary to low and mid elevation shrubland ecosystems, higher elevation coniferous forests of areas like San Emigdio (Mount Pinos), Upper San Gabriel, Upper San Gorgonio, and San Jacinto ecological subsections are now experiencing far fewer fires than was the case before Euro-American settlement (Skinner et al., 2006, Safford and Van de Water, 2013). Much of the high elevation forests around Mount Pinos have not burned in over 100 years and currently have an uncharacteristically high fuel load. While lightning-ignited fires once burned frequently in high elevation mixed conifer and yellow pine forests, fire suppression has succeeded in nearly eliminating wildfire as an ecological driver in these ecosystems (Keeley et al., 2009; Safford, 2007). At many sites, evidence suggests a decline in fire frequency beginning around 1900 and becoming increasingly evident after 1925 (Skinner et al., 2006). Very few fires have occurred in the southern California mountains since the onset of fire suppression, although a number of recent, large and severe fires have received attention (e.g., Keeley et al., 2009). Altered fire behavior due to fire suppression and a changing climate has resulted in the replacement of mixed conifer forest by hardwoods and shrubs in some areas burned by stand-replacing crown fires (Goforth and Minnich, 2008).

VEGETATION

Mediterranean climate regions like southern California exhibit high levels of plant richness and endemism (Cowling et al., 1996; Underwood et al., 2009), yet they are also among those most sensitive to climate and land-use change (Sala et al., 2000). The fragmented landscapes of southern California may limit the ability of rare and endemic species to shift their ranges in response to climate change (Lawson et al., 2010; Underwood et al., 2009). When dispersal is unrestricted, the distribution of vegetation in California is expected to move upslope and poleward, in response to climate change (Fellows and Goulden, 2012; Hayhoe et al., 2004; Loarie et al., 2008). While such long-term shifts are difficult to observe, observations of short-term shifts in response to drought and climate variability can offer us insight into the trends we are likely to see under warmer and drier climates. Kelly and Goulden (2008)compared a 2006-2007 plant survey to a 1977 survey along a 1.44 mi (2314 m) gradient transect in the Santa Rosa Mountains in southern California. They found the average elevation of the dominant plant species rose approximately 213 ft (65 m) between surveys based on analysis of ten plant species. Fellows and Goulden (2012) measured distribution of live and dead trees in the San Jacinto Mountains of southern California to further explore these patterns. They recorded a 121±108 ft (37 ± 33 m) upslope shift in midmontane species distributions following the 2002-2004 prolonged drought period. Both studies attribute this upward 'lean' to small scale climate variability (Kelly and Goulden, 2008; Fellows and Goulden, 2012), although other authors suggest that for at least some of the observed species, the shift may better be explained by self-thinning associated with disturbance history (Schwilk and Keeley, 2012). Given that climate change in the southwestern U.S. is expected to decrease mean precipitation, increase warming and thereby intensify evapotranspiration and drought (Fellows and Goulden, 2012), it is likely that the montane vegetation shifts observed in these studies will be observed on larger spatial and temporal scales in the coming years.

Low and middle elevation shrublands

Climate change is not the sole direct driver of vegetation change in southern California shrublands, rather climate interacts with expanding urban areas, excessively frequent fire and invasion by exotic plants to impact vegetation structure and composition in southern California shrublands. For instance, the interaction of drought and fire on the survival of chaparral species may already be substantial given that resprouted stems are more susceptible to water stress than intact vegetation (Ramirez et al., 2012; Saruwatari and Davis, 1989). Pratt et al. (2014) found an increase in chamise (*Adenostoma fasciculatum*), greenbark Ceanothus (*Ceanothus spinosus*) and toyon (*Heteromeles arbutifolia*) mortality of resprouted vegetation under drought conditions relative to average rainfall years. However other chaparral species, including a drought tolerant obligate seeder, were not affected by drought following fire (Pratt et al., 2014). Post-burn drought may shift the composition and abundance of chaparral species in the short-term and extended drought may lead to type conversion over the long-term. Drought induced canopy dieback can result in biophysical changes at the soil surface, including higher solar radiation and temperature. These changes mock fire and post-fire conditions and can stimulate premature germination of some chaparral shrubs, thereby leading to further shift in species composition (Stephen Davis, USFS Chaparral Symposium).

Coastal sage scrub and chaparral habitats are being invaded by exotic annual grasses and forbs from drier parts of Eurasia. Their abundance on the landscape indicates a degraded ecological condition driven by multiple anthropogenic factors, including short fire return interval (Keeley et al., 2005; Lippitt et al., 2013; Zedler et al., 1983), N deposition (Allen et al., 2014) and climate change (Lenihan et al., 2003). Exotic annual grasses promote themselves at the expense of native vegetation through altered fire regimes (e.g. reduced fuel load and greater ignitability) (D'Antonio and Vitousek, 1992; Davies and Nafus, 2013; Keeley, 2000). Non-native annual species and fast growing native species replace chaparral when fires occur more frequently than about every 10 years, due to the time it takes chaparral species to resprout or produce a viable seed bank (Keeley, 2006; Lombardo et al., 2009). Lippitt et al. (2013) found that 69% of frequently burned (defined as a fire return interval < 10 years) chaparral stands experienced a 50% transformation to a disturbed or converted state; and fire return intervals of less than 5 years resulted in a more complete conversion to exotic annual dominance. Once established, exotic annual grasses constrain native regeneration and are challenging to remove from the landscape (Cox and Allen, 2008; Eliason and Allen, 1997).

Middle and high elevation conifer forests

Fire suppression has been practiced as a federal policy since the early 20th century. In the late 1920's and early 1930's, the Forest Service inventoried and mapped vegetation on National Forest lands in California (Wieslander, 1935). Minnich et al. (1995) revisited Wieslander plots located in mixed conifer forests on the San Bernardino NF, and found that modern forests were almost 80% denser on average, and mean tree size had greatly decreased; tree composition had also shifted such that shade tolerant species like white fir and incense cedar had replaced pines as the dominant species. Less pronounced increases in density occurred in higher and drier Jeffrey pine-dominated sites. Fellows and Goulden (2012) found disproportionately high rates of mortality in larger trees following an extended drought period, suggesting that interactions between fire suppression and increases in climate stress are likely to further decrease average tree size and increase density of small trees in southern California montane forests. Increases in stand density and warming temperatures have also provided more favorable conditions for bark beetle outbreaks (USFS, 2011). Southern California experienced severe mortality due to bark beetle outbreaks in dense stands in 2003-2004, following severe drought (Smith, 2007), and increases in drought conditions are likely to increase beetle-caused mortality in the future (Bentz et al., 2010). The Los Padres had a total of 43,926 acres of canopy dieback, tree mortality and disturbance in 2014, largely mortality was on the Mt. Pinos Ranger District where pinyon, Jeffery and coast live oak were heavily impacted. The acres of affected tree canopy increased by 33, 924 acres from 2013 to 2014 (USFS, 2015).

The effect of drought on forests can extend beyond the drought itself, with decreased growth and incomplete recovery lasting 1-4 years following the cessation of drought conditions (Anderegg et al., 2015). However, tree ring data suggests that legacy effects following drought were not particularly high in California and Mediterranean regions when compared with the rest of the world, and pines exhibited greater drought legacies than oaks (Anderegg et al., 2015).

Drought conditions coupled with the introduction of exotic pathogens, like *Phytophthora ramorum* the causal agent for sudden oak death (SOD), are likely to increase fuel loads and decrease foliar moisture content in Coast Range forests (Kuljian and Varner, 2010; Valachovic et al., 2011). The Basin Complex and Chalk fires of 2008 provided an opportunity to evaluate the effect of increased fuel loads and subsequent change in fire behavior due to SOD on tree mortality. Metz et al. (2013) found a synergistic effect of SOD and fire on the mortality of a typically fire resilient species, the coast redwood (*Sequoia sempervirens*).

WILDLIFE

Changes in climate may have both direct (e.g. thermal stress) and indirect (e.g. changes in species interactions and habitat) effects on wildlife distributions and abundances (Martin, 2007; Rubidge et al., 2011). Direct effects of climate warming are predicted to force species upslope and northward, while indirect effects leave a more complex signature. Studies in other parts of California suggest that wildlife are moving in response to changing climates in order to maintain environmental associations to which they are adapted (small mammals: (Moritz et al., 2008; Rubidge et al., 2011); butterflies: (Forister et al., 2010); birds: (Tingley et al., 2009). Species with a high degree of habitat specialization and/or a smaller natural thermal range are more sensitive to climate change than other species and may be under more pressure to move as climates warm (Gardali et al., 2012; Jiguet et al., 2006). Breeding birds in southern California shifted their distributions upward on average 377-410 ft (115-125 meters) from 1979 to 2005 (Hargrove and Rotenberry, 2011). Most of this shift can be attributed to up-slope encroachment by desert scrub birds rather than range contraction by chaparral birds, suggesting that desert species may be closer to their physiological limits (Hargrove and Rotenberry, 2011). Hargrove and Rotenberry (2011) found that climate plays an important role in limiting the lower distributions of (higher-elevation) chaparral bird species in southern California, thus excluding them from low elevation sites, but a less important role in limiting the upper distributions of (lower-elevation) desert bird species. Biotic interactions, such as competition and predation, play a more significant role in limiting the upper distributions of these lower elevation species, further complicating up-slope migrations in response to climate change.

While direct effects of climate change on the Spotted Owl may be positive (positive reproductive output with increases in minimum nesting season temperatures), owl populations in southern California (data from the San Bernardino mountains) have been declining in recent years, probably due to indirect effects such as drought, disease, and fire-induced habitat loss, as well as isolation, urbanization, and air pollution (Eliason and Loe, 2011; Peery et al., 2012). Another major indirect impact of climate change on wildlife populations is the loss of synchrony between reproductive or migratory phenology and resource availability (MacMynowski and Root, 2007; Seavy et al., 2009). Breeding dates of birds like tree swallows have advanced during the last century (in the tree swallow case, they now occur up to 9 days earlier (Dunn and Winkler) 1999); which may lead to a mismatch in timing of egg laying relative to availability of food. Shifted flowering, fruiting, and seeding times may affect species that rely on these services. Timing of the migration of California overwintering songbirds like Swainson’s Thrush, Warbling Vireo, and Wilson’s Warbler among others has also advanced significantly since 1969 (MacMynowski and Root, 2007). Asynchrony with animal and insect pollinators may also become a significant problem for California plant species (Memmott et al., 2007).

II. Future predictions for trends over the next century linked to climate change

TEMPERATURE & PRECIPITATION

As of today, few published climate change or vegetation change modeling studies have been carried out for southern California as a region. Relatively few future climate modeling efforts have treated areas as restricted as the State of California. The principal limiting factor is the spatial scale of the General Circulation Models (GCM's) that are used to simulate future climate scenarios. Most GCM's produce raster outputs with pixels that are 10,000's of mi^2 in area. There is a need for fine scale climate projections to match the scale at which hydrologic and ecological processes are occurring (Flint and Flint, 2012), yet to be used at finer scales, these outputs must be downscaled using a series of algorithms and assumptions (Thrasher et al., 2013), which adds uncertainty to already uncertain data. These finer-scale secondary products currently provide the most credible sources we have for estimating potential outcomes of long-term climate change for California.

The Basin Characterization Model (BCM) datasets project climate data at a fine scale resolution (270m) and are widely used across the state for research and planning across small geographic regions (Flint and Flint, 2014). The BCM data incorporates various models and emission scenarios to generate 18 climate change projections for the years 2070-2099. Across the 18 projections there is consensus for increasing temperatures in California (1951-1980 compared to 2070-2099), yet the magnitude of warming is unknown (estimates range between <1° C to >6° C). In contrast to temperature, there is uncertainty as to the direction of change for precipitation, with some projections indicating more rainfall across the state and others predicting less (Flint and Flint, 2014).

Other modelling efforts have also found disagreement with respect to the direction of future precipitation projections. For example, a comparison of 21 published GCM outputs that included California found that estimates of future precipitation ranged from a 26% increase per 1.8°F (1°C) increase in temperature to an 8% decrease (Gutowski et al., 2000; Hakkarinen and Smith, 2003). That said, there was some broad consensus: all of the reviewed GCM's predicted warming temperature for California, and 13 of 21 predicted higher precipitation (three showed no change and five predicted decreases). According to Dettinger (2005) the most common prediction is temperature warming by 9°F by 2100 with precipitation remaining similar or slightly reduced compared to today. Most agree that summers will be drier than they are currently, regardless of levels of precipitation. Tague et al. (2009) summarize that in southern California in particular, temperatures are predicted to increase by 2.7 to 9°F (1.5-5°C), with small to moderate changes in precipitation ranging from negative (- 30%) to slightly positive (+10%). Predictions for southern California also include an increase in winter rains, followed by drier summers (Field, 1999; Gabet and Dunne, 2003). The north and south coasts of California are projected to experience the largest increase in humid nighttime heat wave events (Gershunov and Guirguis, 2012).

While not as fine-resolution as projections from the BCM, the most widely cited of the modeling efforts in California is probably Hayhoe et al. (2004). Hayhoe et al. (2004) used two contrasting GCM's (much warmer and drier vs somewhat warmer and drier) under low and high greenhouse gas emissions scenarios to make projections of climate change impact for California over the next century. By 2100, under all GCM-emissions scenarios, April 1 snowfall was down by -22% to -93% in the 6,700-10,000 feet elevation belt and the date of peak snowmelt was projected to occur from 3 to 24 days earlier in the season. Average temperatures were projected to increase by 2 to 4° F in the winter and 4 to 8° F in the summer. Finally, three of the four GCM-emissions scenarios employed by Hayhoe et al. (2004) predicted strong decreases in annual precipitation by 2100, ranged from -3.6 in to -6.2 in (-91mm-157mm); the remaining scenario predicted a 1.5 in (38 mm) increase.

Cayan et al. (2008) uses two climate models; the Parallel Climate Model (PCM1) from the National Center for Atmospheric Research and the Department of Energy, and the Geophysical Fluid Dynamics Laboratory CM2.1 (GFDL) from the National Oceanic and Atmospheric Administration to investigate possible future climate changes in California. Despite global projections for increases in precipitation extremes (Kharin et al., 2013; Kharin et al., 2007; Sun et al., 2007), Cayan et al. (2008) found only modest increases in the number and magnitude of large precipitation events in California. In general, their findings indicate that over the next century temperatures are predicted to increase while precipitation is predicted to remain fairly stable.

Using more local-scale models, Hughes et al. (2011) projected an increase in temperature between the 20th and 21st century at a 12km resolution for the interior desert of southern California, associated with transient climate change of anthropogenic origin. The projected increase in minimum winter temperatures in the desert would cause a decrease in the temperature gradient between the cold desert and warmer air over the ocean, leading to a reduction in the duration and frequency of Santa Ana events during this time span (Hughes et al., 2011). However, Hughes et al. (2011), also predict increased temperature and decreased relative humidity during this same time period, leading to mixed impacts on local climate and wildfire.

HYDROLOGY

The Basin Characterization Model (BCM) takes a HUC-8 watershed approach to predict the fate of water across California into the future (Flint and Flint, 2014). The BCM outputs have been compiled into time series data from the 1920s to the end of the 21st century and include the following hydrologic output variables: recharge, runoff, actual evapotranspiration, climatic water deficit and soil storage (California Climate and Hydrology Change Graphs, 2016). The BCM is currently the best available model for predicting affects to hydrologic function brought about by changing climate.

Miller et al. (2003) found that annual streamflow volumes were strongly dependent on the precipitation scenario, but changes in seasonal runoff were more temperature dependent. Predicted spring and summer runoff was lower in all of the California river basins they modeled, except where precipitation was greatly increased, in which case runoff was unchanged from today (Miller et al., 2003). Runoff in the winter and early spring was predicted to be higher under most of the climate scenarios because higher temperatures cause snow to melt earlier. Flood potential in California rivers that are fed principally by snowmelt (i.e., higher elevation streams) was predicted to increase under all scenarios of climate change, principally due to earlier dates of peak daily flows and the increase in the proportion of precipitation falling as rain (Miller et al., 2003). Less well understood are the potential changes to river-fed streams, which are much more common in southern California. Timing of peak flow may be expected to advance by up to seven weeks by 2100, depending on the climate scenario (Young et al., 2009). Snowfall in the greater Los Angeles area is projected to decline by 30-42% by mid-century, and

30-60% by the end of the century, dependent on mitigation employed, with greater loss at lower elevations (Fengpeng et al., 2013).

While hydrological changes in snow-dominated areas like the Sierra Nevada, and the higher mountain ranges of southern California will mainly depend on shifts in precipitation patterns, vegetation shifts may play a more central role in changes to southern California hydrology (Tague et al., 2009). Hydrology in semi-arid Mediterranean type ecosystems is largely dependent on climate-vegetation-soil-water interactions, which can vary strongly with temperature and CO2 levels (Tague et al., 2009). Increased temperatures alone will likely reduce net primary productivity (NPP) in Mediterranean ecosystems (Peñuelas et al., 2007). This reduction in NPP would lead to reduced water use, potentially leading to a moderate increase in summer streamflow (Tague et al., 2009). However, when modeled with the increase in CO_2 levels that are driving climate change, impacts of CO_2 will lead to higher biomass and NPP in chaparral ecosystems, and thus higher water consumption, probably far outweighing the losses due to temperature (Tague et al., 2009). Frequency of low streamflow years is projected to be considerably higher with greater levels of atmospheric CO_2, and NPP is projected to be more variable from year to year (Tague et al., 2009). Additionally, rainfall is predicted to occur in higher concentrations in fewer events leading to higher variability and unreliability in meteoric, stream and ground water in a region already subject to the most variable precipitation regime in North America (Dettinger et al., 2011). Warming temperatures are also expected to extend the period of summer drought, and decrease flows in the dry months (Reba et al., 2011). Increased water demand, extended drought periods, and high precipitation variability are likely to increase ecosystem vulnerability in a changing climate.

While vegetation-temperature-CO_2 interactions will play a central role in low-flow shifts, fire may play a central role in high-flow shifts under future climate change (Tague et al., 2009). Increases in fire frequency (see fire section below) are likely to lead to increased streamflow, sediment load, and peak discharges in chaparral ecosystems (Florsheim et al., 1991; Loáiciga et al., 2001; Tague et al., 2009). Increases in fire frequency are likely to decrease plant cover, which in turn will decrease water infiltration into soil, increase surface flow, and lead ultimately to increased soil erosion (Riera et al., 2007). In addition, while overall rainfall may decrease in the coming century, as rainfall occurs in fewer, more intense events, vegetation will not be able to hold onto water as it arrives, further intensifying high-flow and flooding events (Vallejo et al., 2012). Blickenstaff et al. (2013) project significantly increased flooding risk in the Santa Ana river watershed, including an increase in streamflow rates from 134,000 cfs to 239,000 cfs between 1990 and 2070, and what was historically a 200-year flood event becoming a 70-year event by 2070. Increases in extreme hydrologic events across the western U.S. are predicted to be especially pronounced in California (Kim, 2005). Such events could facilitate unprecedented debris flow and landslide events within the region, as evidenced by recent case studies (e.g., (DeGraff et al., 2011; Huggel et al., 2012). Increased variability in streamflow in California is already resulting in – and is predicted to continue to result in – extended wet and dry spells (Pagano and Garen, 2005), with significant economic, social, and biological impacts (Mote et al., 2005).

Changes in vegetation patterns in southern California may further alter the patterns and magnitude of erosion and runoff. Gabet and Dunne (2003) reported that sediment delivery is 38% higher under grassland than coastal sage vegetation conditions in an area of the Transverse Range just north of Santa Barbara, CA. However, in coastal sage, most sediment is delivered by catastrophic processes like slumps, landslides, and debris flows, strongly linked to the occurrence of fires, while soil creep accounts for most sediment delivery in grassland systems (Gabet and Dunne, 2003). Thus, not only would runoff and erosion rates be higher with vegetation conversion, but the method of delivery would be altered from 'catastrophic to chronic' (Gabet and Dunne, 2003).

FIRE

A temporal pattern of climate-driven increases in fire activity is already apparent in the western United States (Westerling et al., 2006), and modeling studies specific to California expect increased fire activity to persist and possibly accelerate under most future climate scenarios, due to increased growth of fuels under higher CO_2 (and in some cases precipitation), decreased fuel moistures from warmer dry season temperatures, and possibly increased thundercell activity (Lenihan et al., 2008; Lenihan et al., 2003; Miller and Urban, 1999; Price and Rind, 1994; Westerling and Bryant, 2006). Westerling and Bryant (2008) predict a 10-35% increase in large fire risk by midcentury in California and Nevada, and Westerling et al. (2011) projected increases in burned area of up to 2.5 times the current levels in southern California shrublands and forestlands by the end of the century (Figure 4).

Temperature has been shown to strongly influence fire frequency and area burned, and increased temperatures will lead to increased fire frequency and size (Guyette et al., 2012; Pausas, 2004; Spracklen et al., 2009) and can also change the seasonality of fire. Brown et al. (2012) predict that drier spring and warmer summer temperatures will elevate fire danger in April and May leading to an increase in fires during this historically low season. This uncharacteristic fire season was illustrated by the 2008 Jesusita Fire that burned 8,000 acres and 80 homes in the Santa Barbara front country in early-May (Brown et al., 2012).

The largest fires in southern California occur during Santa Ana wind events that historically occur in fall (Jin et al. 2014). The seasonality of dry offshore winds are predicted to shift from September-October to November-December (Miller and Schlegel, 2006). By mid-century, Santa Ana wind events are

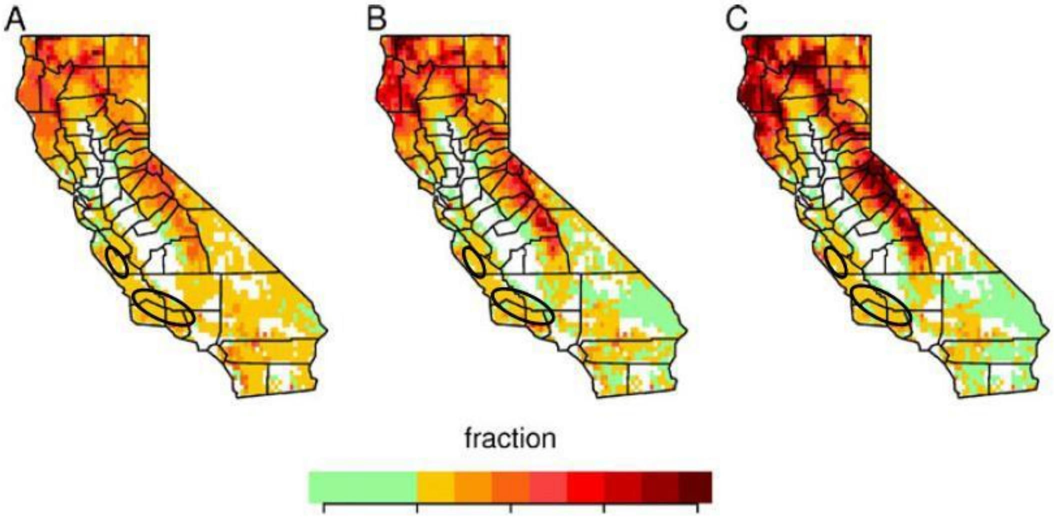

Figure 4. Proportional change in projected mean annual area burned for the 2050-2099 period relative to the mean annual area burned for the reference period (1950-1999) for three climate change scenarios. A) NCAR PCM1= slightly drier than today and warmer, B) CNRM CM3= drier and much warmer than today and C) GFDL CM2.1= much warmer and much drier than today. LPNF region is circled in black. Figure from Westerling et al., 2011.

expected to decrease in frequency (Hughes et al., 2011; Jin et al., 2015; Miller and Schlegel, 2006), yet reductions in relative humidity with higher temperature and increased wind speed may exacerbate fire conditions under Santa Ana wind events in the future (Hughes et al., 2011; Jin et al., 2015). The area burned in Santa Ana wind driven fires are projected to increase by 64% from 1981-2000 time period compared to 2040-2060 (Jin et al., 2015). Likewise, fuel driven fires (non-Santa Ana wind driven) are projected to increase by 77% (Jin et al., 2015).

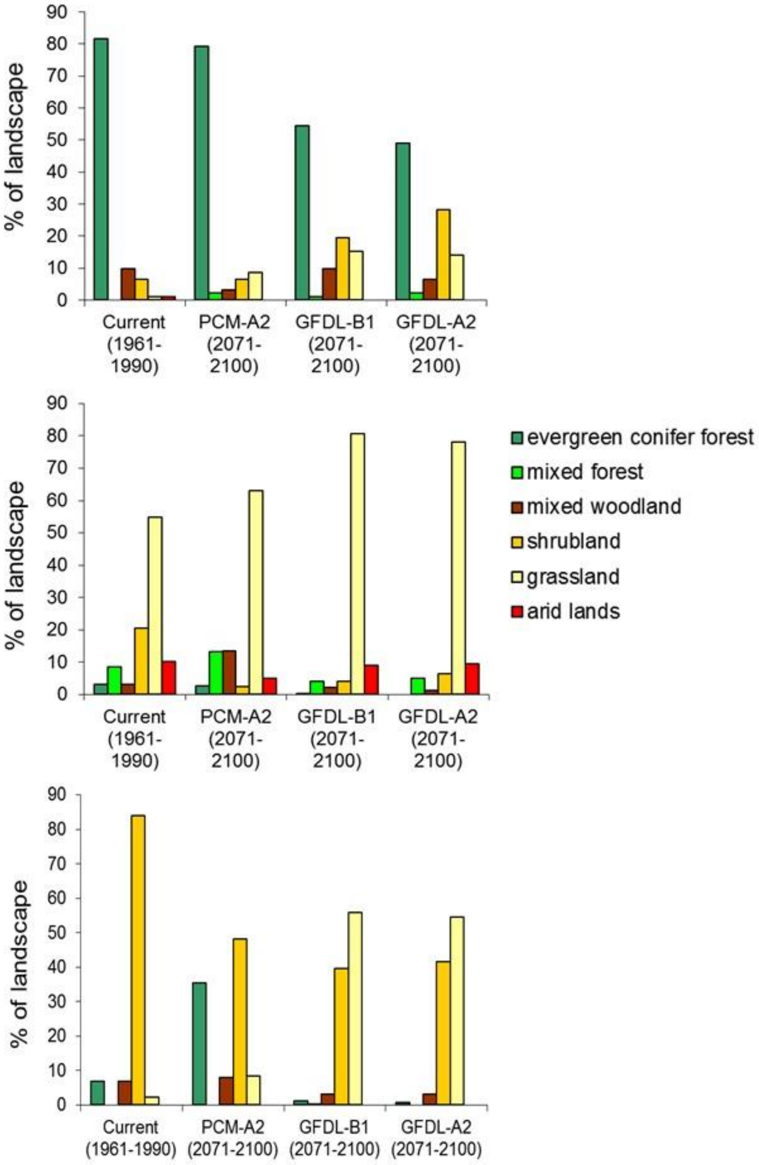

Figure 5. Current (1961-1990) vs. future (2071-2100) projections of vegetation extent for central California coast (top), southern California mountains and valleys (middle), southern California coast ecoregion (bottom). Climate projection scenarios-- **PCM-A2**: ppt=similar to today, temp=<5.5°F increase, **GFDL-B1**: ppt=drier than today, temp=moderate increase, GFDL-A2: ppt=much drier than today, temp=much warmer than today. Original data derived from Lenihan et al, 2008.

Fire regimes are driven principally by the effects of weather/climate and fuel type and availability (Bond and van Wilgen, 1998). Seventy years of effective fire suppression in coniferous forests in the semiarid American West have led to fuel-rich conditions in some habitat types that are conducive to intense forest fires that remove significant amounts of biomass (Arno and Fiedler, 2005; McKelvey et al., 1996; Miller et al., 2009), and most future climate modeling predicts climatic conditions that will likely exacerbate these conditions. Basing their analysis on two GCMs under the conditions of doubled atmospheric CO_2 and increased annual precipitation, Flannigan et al. (2000) predicted that mean fire severity in California (measured by difficulty of control) would increase by about 10% averaged across the state. Vegetation growth models that incorporate rising atmospheric CO_2 show an expansion of woody vegetation on many western landscapes (Lenihan et al., 2003, 2008; Hayhoe et al., 2004), which could feedback into increased fuel biomass and connectivity and more intense (and thus more severe) fires. Fire frequency and severity (or size) are usually assumed to be inversely related (Pickett and White, 1985), and a number of researchers have demonstrated this relationship for Sierra Nevada forests (e.g. (Miller and Urban, 1999; Swetnam, 1993), but if fuels grow more rapidly and dry more rapidly – as is predicted under many future climate scenarios – then both severity and frequency may increase. In this scenario, profound vegetation type conversion is all but inevitable in the coniferous forests types.

Drier summers and increasing high-wind fire weather during the exceptionally dry late summer/early fall, coupled with more frequent human ignitions are likely to increase the frequency and intensity of fires in the region (Field et al., 1999, Gabet and Dunne, 2003, Miller and Schlegal, 2006). Davis and Michaelsen (1995) predict a 17% decrease in the fire return interval for central coastal California (Gabet and Dunne, 2003). In addition, grassland fuels are flashier than shrubland fuels, making both ignition and rapid spread more likely in type converted ecosystems. Thus if conversion of shrublands to grasslands continues as predicted, we may expect larger, more frequent fires in the southern California National Forests (Minnich and Dezzani, 1998).

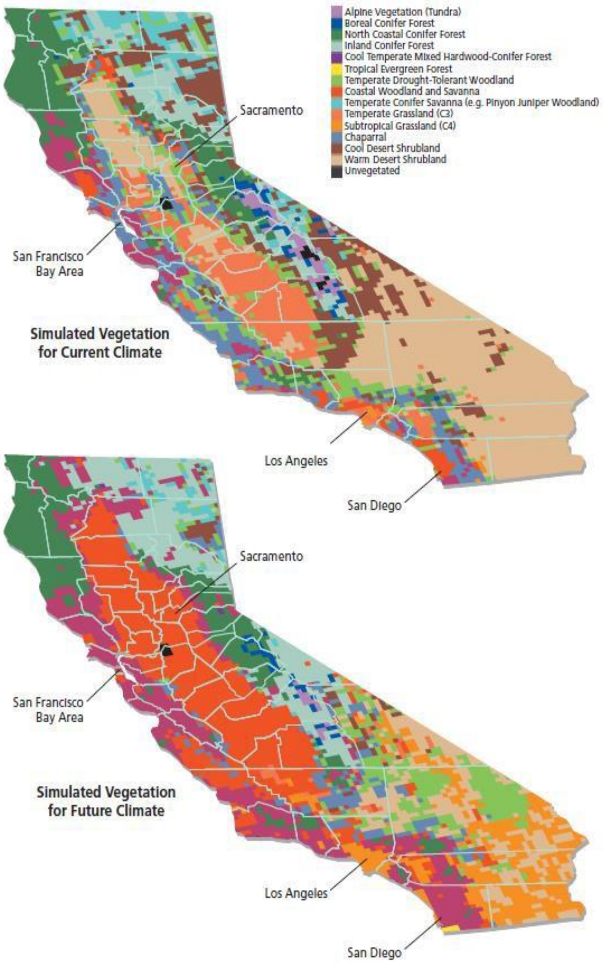

Figure 6. Projected vegetation of California. Top map represents current vegetation in California, and bottom shows projected vegetation in 2099 using MAPSS model. Southern California projections show widespread replacement of shrubland by grassland. Figure from Fields et al., 1999.

VEGETATION

Lenihan et al. (2003, 2008) used a dynamic ecosystem model ("MC1") which estimates the distribution and the productivity of terrestrial ecosystems such as forests, grasslands, and deserts across a grid of 100 km^2 (38.6 mi^2) cells. To date, this is the highest resolution at which a model of this kind has been applied in California, but it is not of high enough resolution to be applied to the LPNF as a unit. Based on their modeling results, Lenihan et al. (2003, 2008) projected that forest types and other vegetation dominated by woody plants in California would migrate to higher elevations as warmer temperatures make those areas suitable for colonization and survival. Under PCM-A2, their most neutral future scenarios, Lenihan et al. (2003, 2008) projected a general expansion of grassland and some expansion of mixed evergreen woodland in southern California. With higher nighttime minimum temperatures, broadleaf trees (especially oak species) were predicted to replace conifer-dominated forests. Under their drier future scenarios, Lenihan et al. (2003, 2008) predicted that grasslands would expand, and that shrub and tree-dominated vegetation would decline (Figure 5). An expansion of shrublands into conifer types was also predicted, due to drought and increases in fire frequency and severity, but increasing fire frequency in the southern California coastal area may replace much of the shrubland with grassland, continuing an a historical trend. Hayhoe et al. (2005) also used the MC1 ecosystem model to predict vegetation and ecosystem changes under a number of different future greenhouse gas emissions scenarios. Their results were qualitatively similar to the Lenihan et al. (2003, 2008) results.

Coupled climate-vegetation models predict the expansion of savanna grassland communities at the expense of shrublands in California foothills (Field et al., 1999). Over the next century, grassy savanna communities may replace shrublands entirely in the southern Coast Ranges (Field et al., 1999, Gabet and Dunne, 2003; Figure 6). Damage from pollutants like ozone and nitrogen oxides may be interacting with changes in climate and fire patterns to cause expansion of exotic grasslands into current shrublands in areas like Riverside and San Diego counties (Field et al., 1999).

Endemic plant species that specialize in uncommon or sparsely distributed habitat (e.g. gabbro soils, montane meadows) will have difficulty responding to changing climatic conditions by migrating (Conlisk et al., 2013). Such narrowly distributed species are also at high risk due to disturbances like fires or floods that may extirpate entire populations. Endemic species in California are expected to move northward and toward the coast, resulting in a continued rich endemic flora along the central western coast of the state (Loarie et al., 2008). Climate induced reductions in suitable habitat may also disproportionately affect long-lived obligate seeding shrubs which are sensitive to changes in temperature and drought severity (Lawson et al., 2010). Lawson et al. (2010) predicted suitable habitat loss of between 70% and 95% for the obligate seeder *Ceanothus verrucosus* in southern California in the coming century. In addition to habitat loss due to changes in temperature and precipitation, such species may suffer further declines if fire return intervals fall below 20 years (Lawson et al., 2010) which seems likely to occur given the combination of climate warming and human population growth that southern California is experiencing. High fire frequency can have multiple negative effects on Mediterranean type shrublands, including: preventing obligate seeding species from replenishing seed banks; depleting starch reserves in resprouting species; and favoring weedy or invasive species (Pausas, 2004).

Shrublands in the south and central coast are expected to decline, 26.4% (5,658 km^2) and 15.2% (1,347km^2) respectively, from land use conversion by 2080 (Riordan and Rundel, 2014). When considering land use and climate change, Riordan and Rundel (2014) predict northern habitat expansion and southern contraction of coastal sage scrub over the next century. The interacting effect of land use change and climate varies greatly by taxa, climate scenario and dispersal ability (Riordan and Rundel, 2014). With limited dispersal, all 20 of the modeled species experienced range reductions, yet with unlimited dispersal, only 50% of the species experienced habitat reductions, with the habitat for some species increasing >100% (e.g. *Rhus integrifolia* and *Encelia california*).

WILDLIFE

Significant changes in California's terrestrial fauna and flora are projected over the next century due to climate change effects on temperature, precipitation, and resulting habitat distributions. Stralberg et al. (2009) developed current and future species distribution models for 60 bird species and found that novel avian assemblages with no modern analogue could occupy over half of California. This implies a dramatic reshuffling of avian communities and altered patterns of species interactions. A total of 128 out of 358 (36%) of California's bird species of "special concern" (rare, threatened, endangered, or experiencing significant decline; (Shuford and Gardali, 2008) were ranked as vulnerable to climate change, including the western yellow-billed cuckoo, gray vireo, cactus wren, and willow flycatcher (Gardali et al., 2012). Based on bioclimatic models, Lawler et al. (2010; 2009) projected high vulnerability of California's amphibian fauna (>50% change in species) and moderate vulnerability of California's mammalian fauna (10-40% change) under a high greenhouse gas emissions scenario by the end of the century. In a similar study, Loarie et al. (2008) projected that 2/3 of California's native flora will experience >80% reduction in range size by 2100. Preston et al. (2008) predict decreases in suitable habitat for the endangered quino checkerspot butterfly and threatened California Gnatcatcher of between 12% and 100% depending on the climate model. Suitable habitat was predicted to shift eastward in southern California, toward higher elevations.

Some invasive species, like the argentine ant, are limited in distribution in southern California by night-time-minimum temperatures (Menke et al., 2007). Increasing minimum temperatures will likely facilitate the spread of argentine ants, leading to decreases in native ant diversity, with cascading impacts (Menke et al., 2007). Thus, we are likely to see an overall decrease in suitable habitat for some native wildlife species, coupled with increased suitability for some invasive species, leading to potential changes in animal community composition in southern California National Forests.

Hydrologic effects of climate change will likely alter wildlife species interactions. Those aquatic species with a competitive advantage in colder waters will likely suffer losses due to both thermal stress and increased competition as water temperatures rise (Kennedy et al., 2009; Rahel et al., 2008). Increasing water temperatures may favor invasive fish species like carp and bass that survive well in warmer streams, while threatening native species like steelhead and mountain yellow-legged frogs that require cooler water streams. Additionally, sensitive benthic invertebrate populations may also be reduced by increases in stream sediment caused by more frequent large and severe wildfires that are likely to be associated with climate warming (Oliver et al., 2012). Decreases in August streamflow likely to be caused by increased CO_2 levels (leading to higher vegetation water-use) associated with climate change could have negative implications for habitat suitability and availability for Steelhead (Tague et al., 2009). Larger effects will likely be observed in smaller streams (Oliver et al., 2012).

As the loss of synchrony between reproductive or migratory phenology and resource availability becomes more pronounced, for species like bats that have specialized diets and carefully balanced energy budgets (e.g. Pallid an Townsend's big-eared bats on the Los Padres), a shift in the timing of invertebrate prey availability could result in reduced survival or fecundity (Halofsky et al., 2011). Species that rely on berries, acorns or conifer seeds as a food source may suffer in areas where source plant species produce less food due to climate stress.

While wildlife species are expected to shift their distributions in response to changing climate and habitat availability, this may be challenging for many species in southern California, where urban and exurban development have led to pronounced habitat fragmentation. With diminished ability to migrate, wildlife species may not be able to follow shifts in the vegetation on which they depend for habitat or food resources, or may be trapped in areas where their food sources begin to decline. For example, predators like mountain lions require the spatial complexity of shrublands and/or forests for cover to move, sleep, and hunt and they actively avoid grasslands (Burdett et al., 2010; Ordeñana et al., 2010). Thus, they may suffer declines in the southern California National Forests, where they are already threatened by habitat loss and fragmentation, if the proportion of grassland habitat increases in accordance with projections. Species like the desert bighorn sheep, which already have small populations and limited habitat, will be particularly sensitive to added stressors brought on by climate change, including thermal stress, potential reduction in food sources, and shifts in suitable habitat areas (Epps et al., 2004). Results of the thermal, hydrologic, and habitat changes associated with climate change in this fragmented landscape may lead to ever increasing risk of extirpation of small, isolated populations of wildlife.

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