CALIFORNIA'S FOURTH
CLIMATE CHANGE
ASSESSMENT

Central Coast Region Report

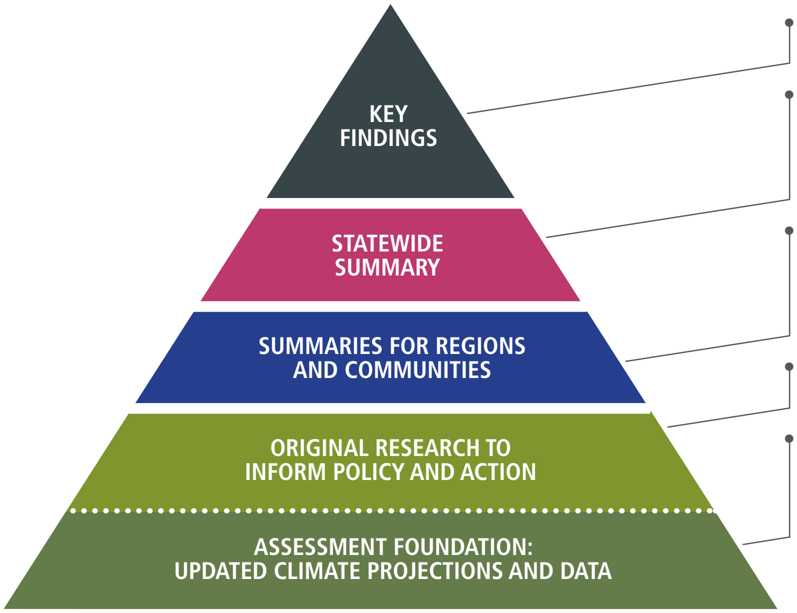
Coordinating Agencies:

CALIFORNIA'S FOURTH
CLIMATE CHANGE
ASSESSMENT

Introduction to California's Fourth Climate Change Assessment

California is a global leader in using, investing in, and advancing research to set proactive climate change policy, and its Climate Change Assessments provide the scientific foundation for understanding climate-related vulnerability at the local scale and informing resilience actions. The Climate Change Assessments directly inform State policies, plans, programs, and guidance to promote effective and integrated action to safeguard California from climate change.

California's Fourth Climate Change Assessment (Fourth Assessment) advances actionable science that serves the growing needs of state and local-level decision-makers from a variety of sectors. This cutting-edge research initiative is comprised of a wide-ranging body of technical reports, including rigorous, comprehensive climate change scenarios at a scale suitable for illuminating regional vulnerabilities and localized adaptation strategies in California; datasets and tools that improve integration of observed and projected knowledge about climate change into decision-making; and recommendations and information to directly inform vulnerability assessments and adaptation strategies for California's energy sector, water resources and management, oceans and coasts, forests, wildfires, agriculture, biodiversity and habitat, and public health. In addition, these technical reports have been distilled into summary reports and a brochure, allowing the public and decision-makers to easily access relevant findings from the Fourth Assessment.



- A concise summary of the Fourth Assessment's most important findings and conclusions.
- An in-depth report on how California's people, built environment, and ecosystems will be impacted by climate change and how we can proactively adapt, based on the Fourth Assessment's findings.
- Reports summarizing Fourth Assessment findings to provide a state of the science for nine regions, the ocean and coast, tribal communities, and climate justice in California.
- Academic research that provides robust and detailed results on resilience and vulnerability to climate change.
- A shared foundation of updated climate change projections, data and ecosystem models developed for use by Assessment authors to permit cross-comparability of results and ensure the findings consider a robust range of future climate conditions. These data are available to the public via Cal-Adapt.org.

All research contributing to the Fourth Assessment was peer-reviewed to ensure scientific rigor as well as, where applicable, appropriate representation of the practitioners and stakeholders to whom each report applies.

For the full suite of Fourth Assessment research products, please visit: www.ClimateAssessment.ca.gov

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Central Coast Region

The Central Coast Region Summary Report is part of a series of 12 assessments to support climate action by providing an overview of climate-related risks and adaptation strategies tailored to specific regions and themes. Produced as part of California's Fourth Climate Change Assessment as part of a pro bono initiative by leading climate experts, these summary reports translate the state of climate science into useful information for decision-makers and practitioners to catalyze action that will benefit regions, the ocean and coast, frontline communities, and tribal and indigenous communities.

The Central Coast Region Summary Report presents an overview of climate science, specific strategies to adapt to climate impacts, and key research gaps needed to spur additional progress on safeguarding the Central Coast Region from climate change.

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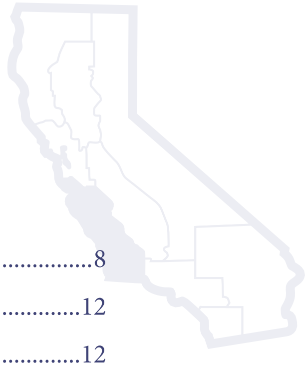

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Highlights

The Central Coast Region is notable for its extensive natural ecosystems, many of which will be impacted by climate change. Hardwood forests, scrublands, and herbaceous grasslands comprise most of its land cover, with significantly less intensive agriculture and small-to medium-sized cities in the region. There is a strong demand for development in rural areas and agriculture is being developed on lands formerly supporting grazing or natural vegetation. The region continues to reflect an economic and social disconnect between prosperous coastal communities and agricultural areas with many low-income farm workers, inequalities that may result in disadvantaged groups suffering disproportionately from the impacts of climate change

Climate changes that will affect the Central Coast include:

- Maximum and minimum temperatures for the Central Coast will continue to increase through the next century, with greater increases in the inland region. Precipitation is expected to increase slightly, but precipitation variability will increase substantially.
- The future of fog is uncertain because system feedbacks and their response to climate change are not well characterized. Fog can be intercepted by coastal zone flora (which obtain up to one-third of their moisture from fog) and can also prevent low stream flows, which can keep salmonids from drying out during dry periods.
- Periodic El Niño events dominate coastal hazards across the Central Coast while atmospheric rivers, expected to increase, are the dominant drivers of locally-extreme rainfall events.
- Recently observed and projected acceleration in sea level rise (SLR) poses a significant threat to the regions' coastal communities. Future flooding is also a serious concern. A recent study suggests that approximately 12,000 residents and $2.4 billion in property could be exposed to flooding due to SLR and storms in Santa Barbara County by the end of the century. A similar level of exposure was predicted for Monterey County.
- Projected future droughts are likely to be a serious challenge to the region's already stressed water supplies.
- Frequent and sometimes large wildfires will continue to be a major disturbance and post-fire recovery time may be lengthened. The 2017-2018 Thomas Fire led to tragic loss of life and huge social cost, and may be representative of future devastating fires and post-fire effects from climate change
- Central Coast native plants are a large part of the world's floristic provinces. Plant species responses to climate change will in general depend on the climate in which a population evolved and its own unique climate tolerances. Coastal shrublands resilience depends on climate effects to physiological responses that are modified by biotic interactions and the extent of anthropogenic land use. Grasslands closer to the coast will be less affected than interior grasslands where warming is already documented.
- Climate change outcomes for forests will depend largely on multiple abiotic drivers (increased air temperatures, altered fog patterns, changes in winter precipitation), and biotic factors (invasive species and insect and pest outbreaks).
- Terrestrial wildlife is already experiencing local extinctions. Species may have robust climate refugia in the region's mountains characterized by cooler temperatures and higher levels of precipitation.
- The aquatic life of streams and rivers are threatened by projected extreme swings from drought to floods, and exacerbated by fire and erosion that buries habitat in sediments. Climate impacts can threaten the survival of already endangered Steelhead and Coho salmon, and further reduce the diversity and abundance of sensitive aquatic insects.

- Estuarine systems will be affected by accelerated SLR, warming of water and air, ocean acidification, and changes in runoff. Some Central Coast marshes may drown or become shallow mudflats, leading to a loss of the ecosystem services that marshes provide, including carbon sequestration.
- Many beaches will narrow considerably. As many as two-thirds will be completely lost over the next century, along with the ecosystems supported by those beaches. The landward erosion of beaches will be driven by accelerating SLR combined with a lack of ample sediment, effectively drowning the beaches between the rising ocean and the backing cliffs and/or urban hardscape.
- Water supply shortages, already common during drought, will be exacerbated. Higher temperatures may result in increases in water demand for agriculture and landscaping. Reduced surface water will lead to increases in groundwater extractions that may result in increased saltwater intrusion. Lower surface flows will lead to higher pollutant concentrations and will impact aquatic species.
- Impacts to the region's public health include increases in heat-related illnesses for agricultural workers, harmful particulate matter from wildfires, and an increase in ground-level ozone. Infectious/Vector-borne diseases include an increase in Valley Fever and Pacific Coast tick fever, and an increase in harmful algal blooms will have detrimental effects on animals and people exposed to toxins released from the algae.
- Residential electricity demand is likely to be affected by more frequent heat waves due to increases in cooling requirements, and warming temperatures are likely to affect electricity supply from gas-fired plants.
- Agricultural production is highly sensitive to climate change, including amounts, forms, and distribution of precipitation, changes in temperatures, and increased frequency and intensity of climate extremes. The Salinas Valley is identified as one of the most vulnerable agricultural regions under climate change.

To adapt to climate change, cities, counties and community groups have completed assessments of local vulnerabilities and engaged in climate change planning and on-the-ground adaptation projects are being implemented. This report offers regionally relevant recommendations for climate adaptation supported by the latest research including:

- Targeted management that maximizes genetic diversity within native species populations.
- Flooding agricultural fields for irrigation and groundwater recharge, increasing use of recycled water, and establishing drought reserves.
- Increasing the elevation of streets, bridges, and rail lines, as well as relocating at risk sections of roads and rail lines farther inland to guard against predicted sea level rise and storm surges. Remapping of flood zones is being considered and some areas may need to be returned to a natural state.
- Allowing space for inland migration of coastal ecosystems (including establishment of inland migration corridors). Implementing 'soft' nature-based shoreline protection solutions. Shifting community development inland.
- Strategic augmentation of protected lands could help improve the climate resilience of native plants.
- Recovering stream and estuarine habitat quality for the spawning and survival of salmon species.

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Introduction to the Central Coast

Mark Snyder, Ruth Langridge,
Monique Myers

The counties included in this report are Santa Barbara, San Luis Obispo, Monterey, San Benito, and Santa Cruz, with some information for the northern part of Ventura County (Figure 1, Table 1). Tourism, power and oil production, agriculture, and related food processing activities are the major industries (Central Coast RWQCB 2018) in this region. There are University of California campuses in Santa Barbara and Santa Cruz, and California State University campuses in Monterey Bay and San Luis Obispo.

FIGURE 1

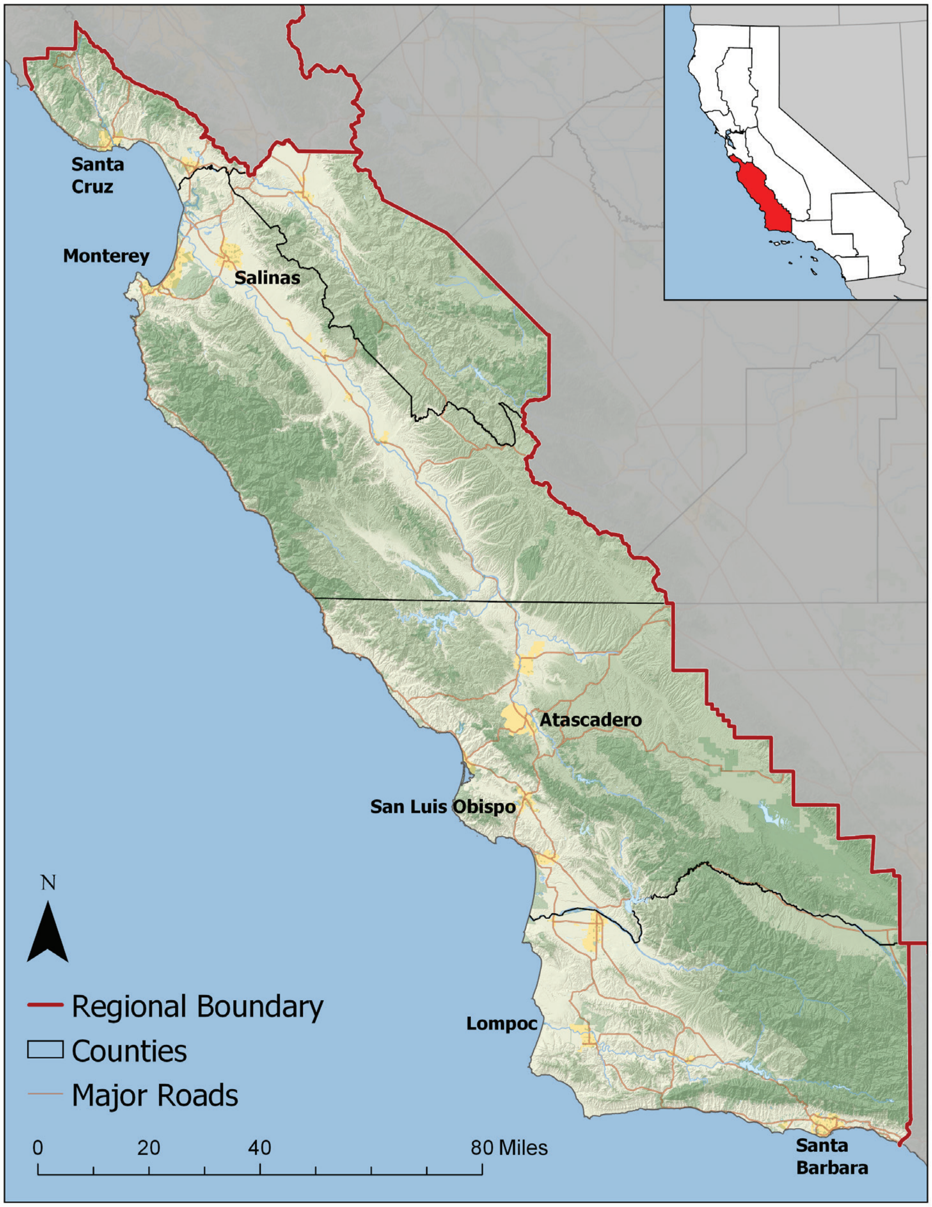


TABLE 1: CENTRAL COAST COUNTIES

COUNTY	COUNTY SEAT	POPULATION (US CENSUS BUREAU 2016)
San Benito	Hollister	59,414
Santa Cruz	Santa Cruz	274,673
San Luis Obispo	San Luis Obispo	282,887
Monterey	Salinas	415,055
Santa Barbara	Santa Barbara	446,170
Ventura	Ventura	849,738

Chumash and other Native Americans originally inhabited the Central Coast as far back as 10,000 BC. Many settlements were coastal, with significant settlements near the mouth of Morro Creek and Los Osos Creek (Hogan 2018).

Climate reflects the region's varied geography and topography. The highest peaks in the Santa Lucia Mountains form a wall behind coastal hillsides that traps cooler marine air, affecting air temperatures, humidity and other climate factors. The advection of marine stratus layers over land moderates the coastal climate by reducing temperatures, raising humidity, and supplying water to the landscape (Potter 2014).

Annual average precipitation varies depending on location and generally decreases from north to south. Coastal mountain ranges in Santa Cruz and Monterey County receive very high amounts of annual precipitation (up to 70 inches), while interior locations receive 10 inches or less per year. Temperatures vary depending on distance from the coast and elevation. Coastal temperatures are lower, while inland and higher elevation areas experience a greater range of temperatures (Peterson and Vose 1997).

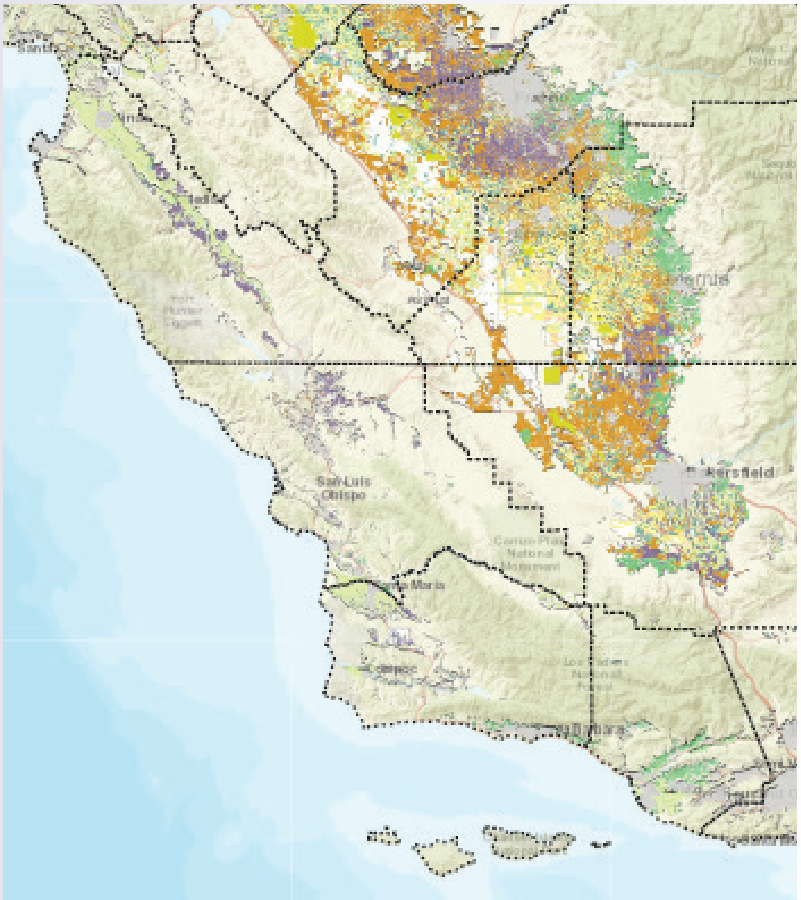
Land Cover is dominated by natural landscapes that comprise over 75 percent of the land cover, and the Central Coast is part of California's Mediterranean biome, a hotspot of biodiversity (Rundel et al. 2016, Stein et al. 2000). The region contains numerous endemic, federally-listed, and sensitive species – such as the coastal dunes milk-vetch, found only along 17-Mile Drive in Pebble Beach on the Monterey Peninsula (California Department of Fish and Wildlife 2018) – that could be highly vulnerable to climate change (Conservation International 2018, DFG 1988).

Box 1: Land cover in Central Coast Region

The Central Coast is dominated by extensive natural ecosystems, many of which will be impacted by climate change. Hardwood forests, scrublands and herbaceous grasslands comprise most of its land cover, with intensive agriculture and small to medium sized cities less than 5 percent of land cover (Figure 1).

There is a strong demand for development in rural areas and agriculture is being developed on lands formerly supporting grazing or natural vegetation (Newman et al. 2003, CA Coastal Commission 2013). These land use changes will contribute to additional impacts under a changing climate.

FIGURE 2



Central Coast Land Use Cover Map. Colored and gray areas are developed land.
Source: CADWR Land Use Viewer

There are no large cities in the region. Municipalities include medium size cities, very small towns with populations of less than 2,000, and cities embedded in agricultural areas such as Watsonville in the Pajaro Valley. Salinas is the largest city with a population of approximately 157,000 (2016). Many coastal areas are tourist destinations.

Box 2: Central Coast Communities

The region continues to reflect an economic and social disconnect between prosperous coastal communities and inland agricultural areas with many low-income farm workers (Frank 2015, Lewis 2016). Available evidence indicates that these initial inequalities can result in disadvantaged groups suffering disproportionately from the adverse effects of climate change (Islam and Winkel 2017).

Although total agriculture land cover is small compared to natural landscapes, in 2016 the total value of agricultural production (Santa Cruz, San Benito, Monterey, San Luis Obispo, and Santa Barbara Counties) totaled $7.6 billion (Tourte 2018). Unique climatic niches and soil types are ideal for year round agriculture and the production of fruits, vegetables, and seed crops. The region is known for its premium wine grape production located mainly in San Luis Obispo and Santa Barbara counties. Vegetable crops were valued at $2.8 billion in 2018, an indication of their significant contribution to coastal agriculture. Top crops in Monterey County, the leader in agricultural production for the Central Coast, include lettuce, strawberries, broccoli, nursery and cut flowers, and wine grapes. Organic agriculture is also prominent in the region (Tourte 2018).

Native American lands include the Santa Ynez Reservation in Santa Barbara County, the Salinan Tribes' ancestral territory in the southern Salinas Valley and the Santa Lucia range, and the Amah Mutsun Tribal Band, whose Land Trust stewards the area from Año Nuevo in the north, along the ridge-lines and west slope of the Santa Cruz Mountains to the Pacific Ocean and Monterey Bay, south to the Salinas River, and inland to include the Pajaro and San Benito watersheds.

Report organization: Sections 2,3 and 4 detail the climate science, natural systems science, and community impacts and adaptations for the Central Coast Region. Section 5 presents a case study of the Thomas Fire and its impacts, including subsequent debris flows, and includes discussion of how climate change will affect future wildfires along the Central Coast. Section 6 identifies knowledge gaps for future research.

Central Coast Climate Science

This section reviews the climate science for the Central Coast Region – including temperature, precipitation, fog, extreme storm events, and extreme drought events – and then discusses the physical impacts of these climate changes including sea level rise, floods, wildfire, and sediment accumulation.

Temperature and Precipitation

Mark Snyder, Neil Berg

INTRODUCTION

This section describes the temperature and precipitation projections developed for the Fourth Assessment, which are applied to the Central Coast Region. Thirty-two of the latest generation of global climate models (GCMs) were downscaled to a resolution of approximately 6 km using the Localized Constructed Analogues (LOCA) method (Pierce et al. 2014). 10 of these 32 GCMs were prioritized for use in the Fourth Assessment, which are used in the figures in this section. Moreover, 4 of those 10 GCMs were further identified as being representative of the entire model ensemble[1], and are detailed in tables in this section.

Daily maximum and minimum temperature and daily precipitation were all downscaled for the Assessment (Pierce et al. 2018). The dataset includes a historical period of 1976-2005 and future projections spanning 2006-2100 under two greenhouse gas emissions scenarios. The first, Representative Concentration Pathway (RCP) 4.5, represents a mitigation scenario where global CO2 emissions peak by 2040. The second, RCP8.5, represents a business-as-usual scenario where CO2 emissions continue to rise throughout the 21st century (van Vuuren et al. 2011). The downscaled climate data were averaged for each of the five Central Coast counties over three thirty-year future time periods and one historical time period for both the RCP4.5 and RCP8.5 (Tables 2,3,4,5). Thirty-year periods were chosen to represent reasonable climatologies at different time slices in the 21st century. RCP8.5 scenario results are also compared to the RCP4.5 scenario throughout the section.

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[1] The 4 representative global climate models are: HadGEM2-ES (Warm/Dry), CNRM-CM5 (Cool/Wet), CanESM2 (Average), MIROC5 (Complement).

TEMPERATURE

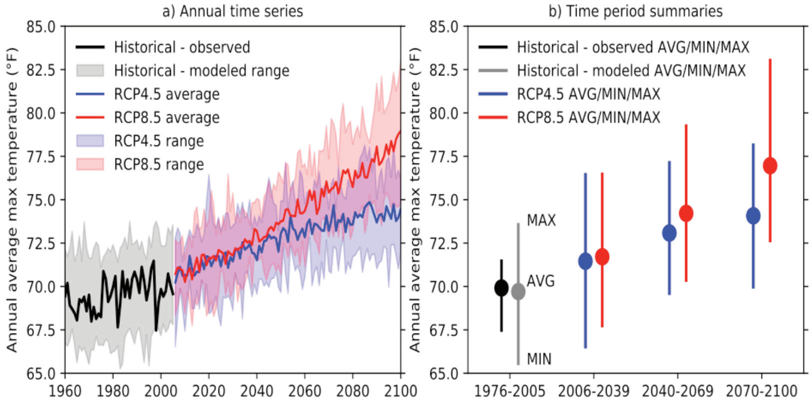
Maximum Temperatures: Overall temperatures are projected to rise substantially in California during the 21st century. Under the RCP8.5 scenario, annual average maximum temperatures across the five counties are projected to increase by 7-8 degrees F by the end of century relative to the historical period (Table 2, Figure 3).

TABLE 2: ANNUAL AVERAGE MAXIMUM TEMPERATURE (DEGREES F)

	HISTORICAL	RCP45			RCP85		
COUNTY	**1961- 1990**	**2010-2039**	**2040-2069**	**2070-2099**	**2010-2039**	**2040-2069**	**2070-2099**
Santa Cruz	67.5	69.3	70.9	71.9	69.6	71.8	74.5
San Benito	70.5	73.1	74.8	76	73.3	76	78.7
Monterey	70	72.1	73.7	74.9	72.4	74.9	77.5
San Luis Obispo	69.8	72	73.6	74.7	72.2	74.8	77.4
Santa Barbara	68.6	70.8	72.3	73.4	71	73.4	76

Annual average maximum temperature (degrees F). From 4 representative global climate models downscaled using the LOCA method.

FIGURE 3

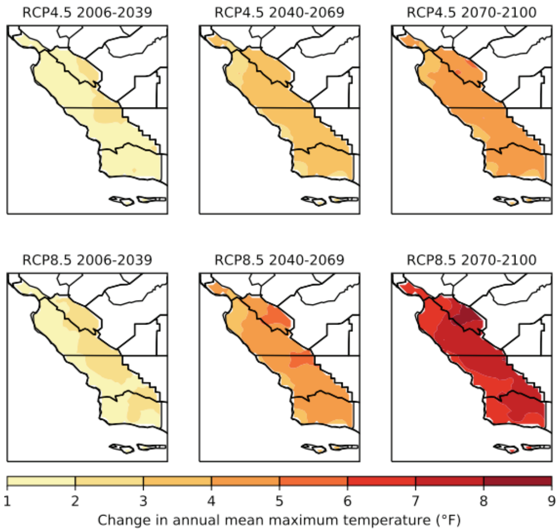


Annual average maximum temperature (F)

Figure 3 represents the changes in the annual mean maximum temperature as an area average across the Central Coast's five counties. By mid-century (2040-2069), the change in the annual mean maximum temperatures is expected to rise between 4-5 degrees F across the five counties, with expected warming on an annual average basis generally consistent across the Central Coast region. There is a spatial pattern to the warming changes that can be seen in Figure 4. Coastal regions warm less than the inland regions, as the ocean provides a buffer to the coastal zone.

Minimum Temperatures: By the end of the century (2070-2099) under the RCP8.5 scenario, annual average minimum temperatures are projected to increase by 7 to 8 degrees F. By mid-century (2040-2069) under the RCP 8.5 scenario, minimum temperatures are expected to rise by 4 to 5 degrees F (Table 3). The increases in minimum temperature are generally consistent across the 5 counties. Multiple sectors will experience the impacts due to the warming trend, discussed in sections 3 and 4.

FIGURE 4



Change in annual mean maximum temperature (ºF)

TABLE 3: ANNUAL AVERAGE MINIMUM TEMPERATURE (DEGREES F)

	HISTORICAL	RCP45			RCP85		
COUNTY	**1961- 1990**	**2010-2039**	**2040-2069**	**2070-2099**	**2010-2039**	**2040-2069**	**2070-2099**
Santa Cruz	42.8	45.1	46.5	47.6	45.4	47.5	50.5
San Benito	41.2	43.7	45.2	46.2	44	46.3	49.3
Monterey	41.5	43.8	45.2	46.2	44.1	46.2	49.2
San Luis Obispo	42.2	44.6	45.9	46.9	44.8	47	49.8
Santa Barbara	43	45.1	46.5	47.4	45.3	47.5	50.2

Annual average minimum temperature (F). From four representative global climate models downscaled using the LOCA method.

Temperature Extremes: Changes in extremely hot temperatures are assessed using the 98th percentile of observed, historical (1961-1990) daily maximum temperatures between April 1 and October 31. The number of extremely hot days exceeding this threshold for each county across the three future time periods and under each emissions scenario are presented in Table 4. Statistics related to annual average maximum temperature and the hottest day of the year shown in Table 5 and Figure 5.

TABLE 4: AVERAGE NUMBER OF DAYS WITH MAXIMUM TEMPERATURE ABOVE A THRESHOLD

	HISTORICAL	RCP45			RCP45		
COUNTY	1961- 1990	2010-2039	2040-2069	2070-2099	2010-2039	2040-2069	2070-2099
Santa Cruz	4.3	6	8	11	6	10	20
San Benito	4.3	13	20	28	14	28	48
Monterey	4.3	10	14	19	11	19	34
San Luis Obispo	4.3	12	18	26	13	27	50
Santa Barbara	4.3	8	12	17	9	17	33

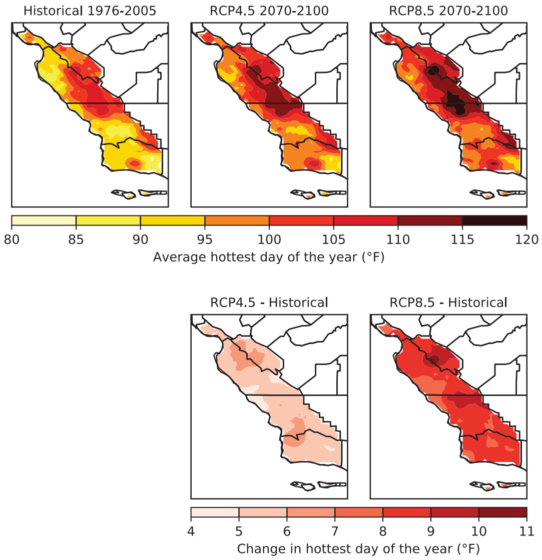
Average number of days with maximum temperature above a threshold. From four representative global climate models downscaled using the LOCA method.

TABLE 5: COUNTY MAXIMUM TEMPERATURES (DEGREES F)

SANTA CRUZ	SAN BENITO	MONTEREY	SAN LUIS OBISPO	SANTA BARBARA
90.1F	94.6F	92.5F	90.3F	87.5F

County average annual maximum temperatures (F).

FIGURE 5



Long-term annual averages of the hottest day of the year

PRECIPITATION

Projections of changes in precipitation in California are more nuanced than projected changes in temperature and have less separation between RCP4.5 and 8.5 scenarios (Pierce et al. 2018). There is a projected increase of year-to-year variability with wetter days during periods of precipitation, but with fewer total days with precipitation. Average annual precipitation under RCP8.5 shows significant increases by 2100 for the state overall as well as on the Central Coast. When combined with higher temperatures, these changes will create significant challenges for the state's water supplies, potentially creating more serious flooding events as well as drier conditions.

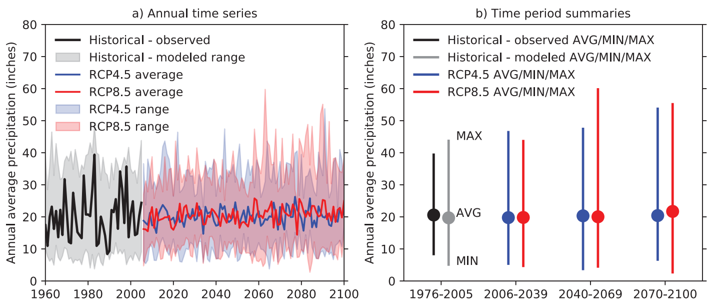
Precipitation generally increases throughout the Central Coast, with the largest increases in the northern part of the region and smaller increases in the inland and southern parts of the region. Historical annual average precipitation varies from a high of 37.2 inches in Santa Cruz County to a low of 16.1 inches in both San Luis Obispo and San Benito counties. Annual average precipitation is projected to increase by 3 to nearly 10 inches across the 5 counties under the RCP8.5 scenario (Table 6, Figure 6).

TABLE 6: ANNUAL AVERAGE PRECIPITATION (INCHES)

	HISTORICAL	RCP45			RCP45		
COUNTY	**1961- 1990**	**2010-2039**	**2040-2069**	**2070-2099**	**2010-2039**	**2040-2069**	**2070-2099**
Santa Cruz	37.2	42.4	40.6	41.3	41.2	41.5	47
San Benito	16.1	18.5	17.3	17.4	17.9	17.6	19.7
Monterey	19.3	22.5	21.1	21.2	21.8	21.4	24.4
San Luis Obispo	16.1	18.7	17.6	17.2	18.2	17.5	19.9
Santa Barbara	17.6	20.3	19.2	18.9	20.6	19	21.5

Annual average precipitation (inches). From four representative global climate models downscaled using LOCA.

FIGURE 6



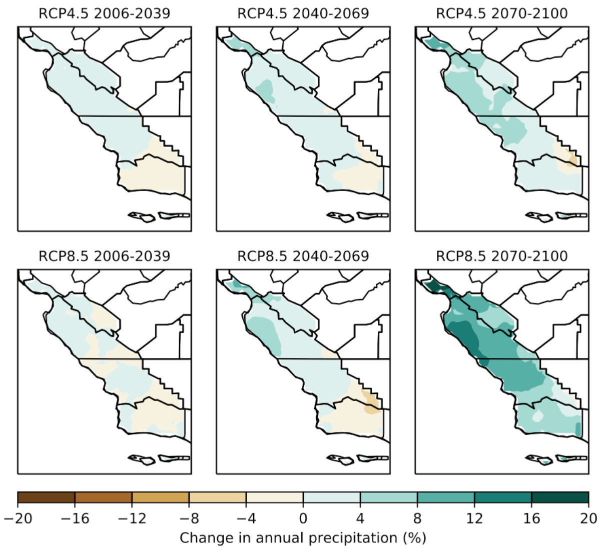
Average annual precipitation

All five counties are projected to see an annual average increase in precipitation, with the more mountainous and coastal counties experiencing the greatest change (Santa Cruz and Monterey). Across the Central Coast region, projections suggest that extremely wet and dry years may become more severe (Swain et al. 2018), while, on the daily time scale, the wettest day of the year is also expected to increase up to 35 percent for some locations by the late-century under RCP8.5 (Figures 7 and 8).

TAKE HOME MESSAGE:

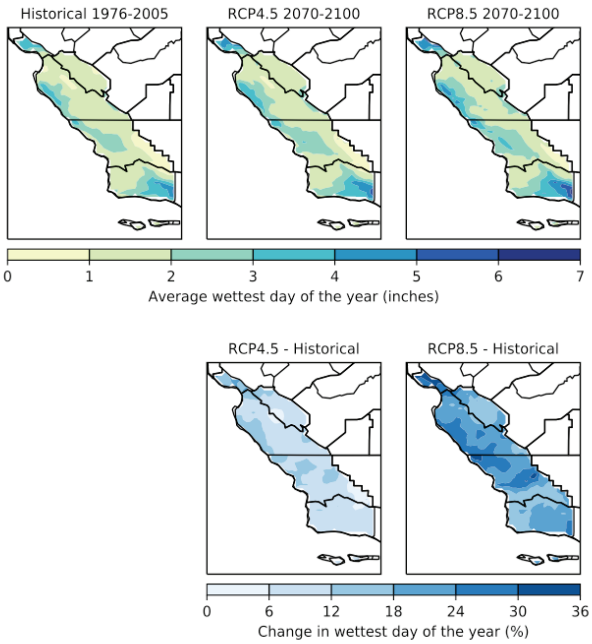
- Maximum and minimum temperatures will continue to increase through the next century, with greater increases in the inland region.
- Average precipitation is expected to increase by a relatively small amount, but the annual variability increases substantially by the end of the century.
- Across the region, projections show that the wettest day of the year will become wetter relative to historical conditions.

FIGURE 7



Change in annual precipitation (%)

FIGURE 8



Long-term annual averages of the wettest day

Fog

Alica Torregrosa

A key feature of the Central Coast region is summertime coastal fog and low clouds (Figure 9). Low clouds reflect 80 - 113 watts/m^2 solar radiation (Matus & L'Ecuyer 2017,,Iacobellis & Cayan 2013), which cools the land surface and reduces plant evapotranspiration and water demand. Fog droplets transported from the marine environment add water to coastal systems and provide up to a third of the water received by coastal ecosystems (Burgess and Dawson 2004, Chung 2017).

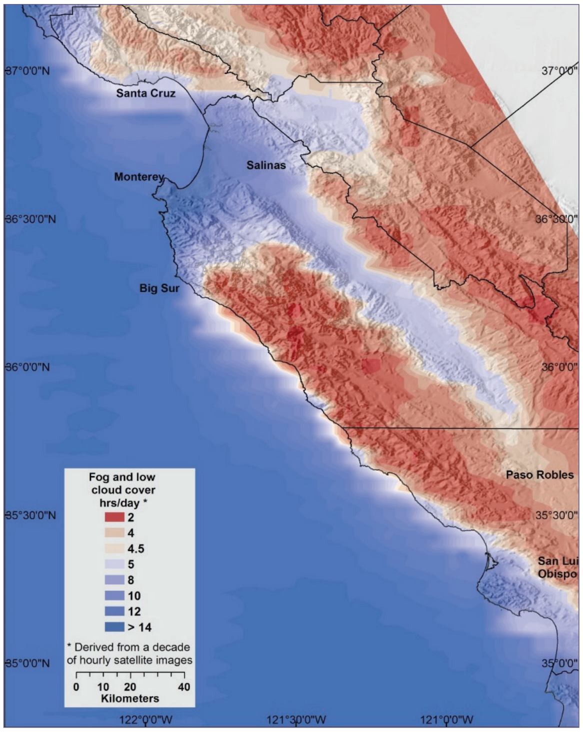
The landscape pattern of coastal fog and low clouds is remarkably stable. Low elevation sites and valleys in the Central Coast region that are open to northwest summer winds, such as Salinas Valley and Monterey Peninsula, average 15 hours/day of summertime fog and low cloud cover (Torregrosa et al. 2016). Areas protected from the wind, such as Santa Cruz, or elevations above the inversion layer that are typically about 500 m, get the least fog. Figure 10 illustrates this with shaded contours of less than 2 hrs/day - red, to more than 14 hrs/day - blue, were generated from ten years (1999 – 2009) of hourly (~ 26,000) day and night digital satellite images from the National Weather Service. The underlying shaded relief shows topography and counties are outlined in black (Torregrosa et al. 2016).

Many endemic species and community types are in sites with high summertime fog frequencies, including coastal redwood (Mooney & Zavaleta 2016), maritime chaparral (Vasey et al. 2014), unique manzanitas, orchids, and salmon. Fog events maintain viable habitat for salmonids in streams that would otherwise dry out in late summer by increasing stream flow by up to 200 percent in low flow coastal streams (Sawaske & Freyberg 2015). Agriculture also benefits when fog and low clouds reduce evapotranspiration rates, reducing crop demand for water and irrigation (Baguskas et al. 2018). Coastal residents are so well acclimated to the cooling effect

FIGURE 9

Artichoke harvesters in the fog. Source: Ocean Mist Farms, Castroville, CA

FIGURE 10



Summertime Fog and low cloud cover - California Central Coast.

of fog and low clouds that when the fog disappeared during the July 2006 heat wave, coastal communities were ill-prepared and suffered higher rates of heat-related mortality than in the inland communities where temperatures commonly reach triple digits (Knowlton et al. 2009)

TAKE HOME MESSAGE:

- Coastal fog reduces summertime temperatures, adds water, and reduces plant water demand.
- Coastal fog formation and onshore transport are a result of complex feedbacks between ocean, air, and land systems and provide a unique focal point to better understand global to local climate change dynamics.
- The future of fog is uncertain because system feedbacks and their response to climate change are not well characterized.

The formation of coastal low clouds and their subsequent movement onshore is deceptively complex and involves highly dynamic ocean, air, and land processes (Koračin 2017, Clemesha et al. 2017). Ocean upwelling, once thought to drive the formation of coastal fog, is secondary to the global atmospheric circulation pattern that situates a North Pacific zone of atmospheric high-pressure. This air mass, as large as a continent and weighed down by gravity, generates inversions under which coastal low clouds form. The frequency and thickness of summertime fog depends on the location of the high-pressure zone, the strength of the inversion, and sea surface temperatures. The summertime winds define how far fog and coastal low clouds move inland.

The future of coastal fog under climate change remains uncertain. Long term fog trends over the coastal ocean from ship observations since 1951 show an increase (Dorman 2017) while fog trends over land show a decrease (Johnstone & Dawson 2010). Fog has decreased over urban areas due to increased heating of impervious surfaces that reduce condensation and raise marine cloud ceilings (Williams et al. 2015). The effect of other land surface changes such as forest fires on fog is unknown. Fog has decreased over agricultural land due to improved air quality, which reduces cloud condensation nuclei (LaDochy & Witiw 2012, Gray et al. 2016). Globally driven changes in air patterns can also cause strong changes in fog at the local level, such as the resilient atmospheric ridge that parked warm dry air over California in August 2017, shutting down the usual pattern of onshore coastal fog advection into coastal ecosystems (see also September 2010 event, (Kaplan et al. 2017)).

Only one dynamic mechanistic model exists to simulate future California coastal fog (O'Brien et al. 2013). It projects a 12- 20 percent reduction in coastal fog by 2070. This model did not include feedbacks to several important mechanisms projected by global climate models to change in the future such as coastal upwelling and shifts in the center of summertime high pressure zones. Simulations of increased sea breeze show increased inland marine air penetration (Wang and Ullrich 2017), but these may also promote higher air turbulence that would dry out and dissipate fog more quickly.

The importance of fog to California's water and energy balance and to human and wildlife well-being is receiving increased attention, although federal support for the nascent Pacific Coastal Fog Monitoring and Research Network was terminated in 2018. Coastal fog was listed as an emerging issue in the 2018 California Indicators of Climate Change report (OEHHA CA EPA 2018). Coastal fog is a visible result of the strongly interacting dynamics of ocean, air, and land systems. It provides an accessible phenomenon to track interdependent climate variables. Learning more about how water changes state in natural conditions will help to unravel the interdependencies of the earth's

system. Understanding the relationships between fog, biodiversity, and human well-being, as we'll as the resilience of fog-dominated ecosystems (Burns 2017), will be essential for making sound technological decisions such as geo-engineering techniques to cool the planet by increasing marine clouds (Ahlm et al. 2017), fog water harvesting as an adaptation to increasingly severe droughts (Fernandez et al. 2018, Domen et al. 2014)we conducted long-term measurements involving three types of mesh using standard fog collectors (SFC, or non-disruptive placement of offshore wind turbines.

Extreme Storm Events

Patrick Barnard

DRIVERS OF EXTREME EVENTS

Along the Central Coast, atmospheric rivers[2] are the dominant drivers of locally-extreme rainfall events and are associated with most major inland floods in California (Dettinger 2011). For example, the large number of atmospheric rivers that struck the Central Coast during the winter of 2016-17 lead to record flooding on the San Lorenzo River in Santa Cruz County (East et al. 2018). Extreme atmospheric river events and severe flooding is expected to increase under projected climate change in California (Dettinger 2011). However, large extratropical storms generate the largest ocean waves (near field and far-field) and therefore are the dominant drivers of coastal flooding, along with tide stage, storm surge, and sea level anomalies (e.g., as during El Niño). The frequency and intensity of extratropical cyclones has been increasing since the mid-1950s in the region (Graham and Diaz 2001).

WAVE CLIMATE

Increases in wave heights over the last several decades have been documented along portions of the U.S. West Coast, including the Central Coast (e.g., Allan and Komar 2006, Wingfield and Storlazzi 2007, Menendez et al. 2008), but these trends have more recently been found to be largely insignificant when adjusted for buoy hardware modifications (Gemmrich et al. 2011). The use of global climate models (GCMs) to determine the future wave climate show a projected poleward migration of storm tracks and generally a slight decrease in wave heights for the Central Coast (and California in general) compared to the historical record (Graham et al. 2013, Erikson et al. 2015).

EL NIÑO

Periodic El Niño[3] events exert a dominant control on coastal hazards across the region, driven by seasonally-elevated water levels as high as 30 cm above normal, and, on average, 30 percent larger winter wave energy in California (Barnard et al. 2015). Past El Niños, including the extreme 1982-83 and 1997-98 events, caused significant erosion along the Central Coast due to the elevated winter waves and water levels, but impacts were more acute along the southern ends of littoral cells due to the more southerly wave approaches driving sand to the north (Storlazzi and Griggs 2000, Sallenger et al. 2002, Barnard et al. 2011, 2015). The powerful El Niño of 2015-16, one of the three

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[2] Atmospheric rivers are long, narrow regions in the atmosphere that transport most of the water vapor outside of the tropics.

[3] El Nino is an irregularly occurring and complex series of climatic changes affecting the equatorial Pacific region and beyond every few years, characterized by the appearance of unusually warm, nutrient-poor water off of northern Peru and Ecuador, typically in late December. An El Niño is said to occur when the trade winds that usually push warm surface water westward weaken, allowing the warm water to pool as far eastward as the western coast of South America.

largest in the historical record, resulted in winter wave energy that was over 25 percent larger than a typical winter along the Central Coast based on observations at the Monterey Bay wave buoy, driving unprecedented beach erosion that was 45 percent higher than normal, using Northern Monterey Bay beaches as a proxy for the region (Barnard et al. 2017, Stevens et al. 2017). However, this event did not feature a southerly wave direction anomaly, which may reflect a long-term pattern of storm tracks migrating progressively northward during successive El Niño events (Barnard et al. 2017), consistent with the multi-decadal trend of poleward Hadley cell expansion[4] (Hu and Fu 2007).

The style, frequency and magnitude of future El Niño events, combined with SLR, will be a key driver of coastal vulnerability in the coming decades. Research to date on future El Niño patterns is largely inconclusive (Collins et al. 2010). A recent study suggests a potential doubling in the frequency of extreme El Niño events (Cai et al. 2014), such as those that occurred in 1982-83, 1997-98 and 2015-16. However, while there has historically been a strong relationship between El Niño and elevated winter wave energy and beach erosion across California (Barnard et al. 2011, 2015, 2017), recent research suggests that the link between El Niño and anomalously high precipitation in California is tenuous, and internal El Niño variability[5] dominates the precipitation signal (Lee et al. 2018).

TAKE-HOME MESSAGE:

- Periodic El Niño events dominate coastal hazards across the Central Coast and will be a key driver of coastal vulnerability in the coming decades.

Extreme Drought Events

Ruth Langridge

California's periodic droughts frequently contribute to water shortages on the Central Coast. Climate change projections of future extreme and prolonged droughts will exacerbate the region's water supply challenges.

DROUGHT CHARACTERISTICS

Droughts are slow-moving environmental hazards due to the ways their effects and impacts accumulate over time (Wilhite 2000, Wilhite and Buchanan-Smith 2005), so it is often difficult to define a drought's onset or when it officially ends. Drought is frequently characterized by anomalies in precipitation or temperature, or a combination of both.

Climate model simulations suggest that droughts lasting several years to decades occurred naturally in California, and tree-ring studies show that California often experienced long periods of dryness, sometimes followed by several wet years (Ingram and Malamud-Roam 2013). Even during "wetter" periods like the 20th century, California experienced extended and multi-year dry conditions (Griffin and Anchukaitis 2014), with at least 10 multi-year droughts during that century.

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[4] As global temperatures rise, the temperature difference between the poles and the equator is likely to decrease, expanding the cell of air circulation adjacent to the equator known as the Hadley Cell.

[5] Internal climate variability may be due to natural internal processes, e.g. El Nino-Southern Oscillation (ENSO).

A persistent, high-pressure ridge in the North Pacific is considered to be the 'proximal' cause of California's 2011-2016 multi-year precipitation deficit (Swain et al. 2014, Wang et al. 2014, Seager et al. 2015). Arctic sea ice loss induced high-latitude changes first propagate into tropics, triggering tropical circulation and convection responses. Decreased convection and upper level divergence in the tropical Pacific then drive a northward propagating wave train, with anti-cyclonic flow forming in the North Pacific. The formation of the ridge is associated with both warmer sea surface temperature (SST) and sea ice loss and is responsible for steering the wet tropical air masses away from California. For the Central Coast, the jet stream doesn't always have enough momentum to break through this ridge of high pressure to allow the mid-latitude westerly winds to carry storms to the Central Coast.

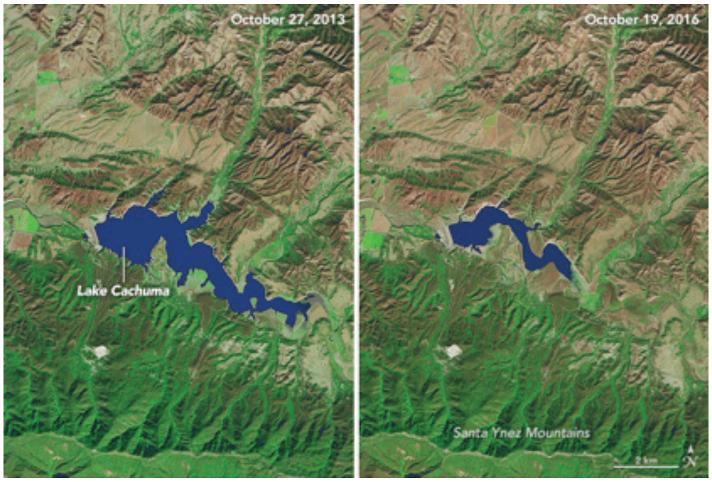
DROUGHT PROJECTIONS

Climate models tend to differ about future precipitation trends and their magnitudes in California. Berg and Hall (2015) analyzed the results of 34 global climate models and concluded that, "in most models the change is very small compared to historical and simulated levels of inter-annual variability." Anthropogenic forcing yields large 21st century increases in the frequency of wet extremes, and smaller but statistically robust increases in dry extremes (Swain et al. 2018). As a consequence, a 25 to 100 percent increase in extreme dry-to-wet precipitation events is projected, despite only modest changes in mean precipitation. During the 2011-2016 drought, record high temperatures and a long-term warming trend generally exacerbated the impacts of limited precipitation, (Berg and Hall 2015a, Diffenbaugh, Swain, and Touma 2015, Williams et al. 2015, Seager et al. 2015).

The fog along the coast that disappears in late summer, as well as increasing temperatures in the future, may also exacerbate the climatic water deficit for watersheds in this region. Without effective adaptations, projected future extreme droughts will challenge the management of the Central Coast region's already stressed water supplies, including existing local surface storage and groundwater recharge as well as imported surface water supplies from the State Water Project which will become less reliable (Kerckhoff et al. 2013), and more expensive (Connell-Buck, Medellín-Azuara, Lund, & Madani 2011, Harou et al. 2010).

On the Central Coast, after the 2016-2017 winter rains following the 2012-2016 drought, water levels in a U.S. Geological Survey (USGS) well climbed only one foot in March 2017, after plummeting 110 feet over the past decade. Lake Cachuma, a major source of surface water in Santa Barbara County, was almost depleted after the 2012-2016 drought, and the rains in 2016-2017 were insufficient in that area to replenish the reservoir which sits in a "rain shadow," and catches only a fraction of the region's rainfall (Figure 11).

FIGURE 11



Lake Cachuma water levels in 2013 and 2016.
Source: Joshua Stevens NASA Earth Observatory/USGS

https://earthobservatory.nasa.gov/NaturalHazards/view.php?id=89110

The adverse effects of the 2011-2016 multi-year drought were not uniformly distributed across California, highlighting differential susceptibility to climate stresses. Water shortages and price hikes affected access to safe, affordable water, with substantial impacts on low-income families and communities burdened with environmental pollution. Disadvantaged communities[6] in areas in the Central Coast region, such as the City of Salinas, were highly affected by water shortages. Drought charges also exacerbated affordability concerns for low-income households (Feinstein et al. 2017).

TAKE-HOME MESSAGE:

- Climate projections show an increase in extreme dry events. While only modest changes in mean precipitation are projected, when combined with increasing temperatures, the management of the Central Coast's already stressed water supplies will be challenging.

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[6] Those with a medium household income of less than 80 percent of the state median

[7] Eustatic relates to or is characterized by worldwide change of sea level.

Physical Impacts of Climate Changes

Sea Level Rise (SLR)

Patrick Barnard

SLR will have widespread adverse consequences for California's coastal resources including coastal flooding and erosion that will affect built structures, coastal agriculture, wetland habitat, sandy beaches, tidal marshes, and estuaries, with these impacts increasing over time. Projected SLR, along with coastal vulnerabilities and adaptations, are thoroughly discussed as part of the Fourth Assessment as well as in the Oceans and Coasts Report (California's Ocean and Coast Summary Report 2018), and therefore only a brief summary is provided here.

TABLE 7: COUNTY HISTORICAL CENTRAL COAST SEA LEVEL RISE (NOAA 2018)

GAUGES	SEA LEVEL RISE
Santa Barbara	1.01 mm/yr, 1973-2016
Port San Luis	0.84 mm/yr, 1945-2016
Monterey	1.39 mm/yr, 1973-2016

Numerous studies document the acceleration of eustatic[7] SLR during the latter part of the 20th century and early 21st century, with rates of ~1-2 mm/yr prior to 1990 as much as tripling to ~3 mm/yr during the satellite altimetry era (1993-present) (e.g., Jevrejeva et al. 2014, Dangendorf et al. 2017). Regional rates of SLR are highly variable in space and time, depending on ocean and atmospheric circulation patterns, gravitational and deformational effects due to land-based ice mass changes, and tectonics and other drivers of vertical land motion (NRC 2012). Historical SLR rates along the Central Coast are consistently on the lower end of the global average, but are documented by just a small number of tide gauges with relatively short records (Table 7).

Moderate variability among these observations can be attributed to factors such as record length, local vertical land motion, and datum issues. However, consistent with the satellite altimetry-observed west coast acceleration of SLR from 2011-2015, each of the Central Coast tide gauges also shows significant acceleration since 2011 due, at least in part, to a shift in low frequency climate variability in the Pacific as well as a strong El Niño peaking in Fall of 2015 (Hamlington et al. 2016).

This recent acceleration of regional SLR follows decades of dynamical SLR suppression across the U.S. West Coast, possibly related to the mode of the Pacific Decadal Oscillation (PDO)[8] (Bromirski et al. 2011). It is unclear how long this recent trend of higher than eustatic rates of SLR will continue for the Central Coast, but it will largely depend on the patterns of shorter (e.g., ENSO) and longer (e.g., PDO) modes of climate variability that drive regional circulation patterns as well as SLR effects.

The regional signal of SLR is further complicated at the local level by variable rates of vertical land motion due to co-seismic and intra-seismic land movement, sediment compaction, marsh accretion, and groundwater fluctuations. However, these local variations have not been robustly assessed for the Central Coast. Spatially variable measurements of vertical land motion based on GPS data and statistical and physical tectonic models, largely attributed to tectonic movement of the San Andreas Fault System, have been determined up through Santa Barbara and southern San Luis Obispo counties (Howell et al. 2016). However, maximum rates of uplift (0.4 mm/yr) and subsidence (0.6 mm/yr) noted in that study are largely insignificant relative to the 93 cm of SLR projected for Los

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[8] The Pacific Decadal Oscillation (PDO) is a robust, recurring pattern of ocean-atmosphere climate variability centered over the mid-latitude Pacific basin.

Angeles for 2100 by the National Research Council (2012), equating to a maximum of 3.4 cm of uplift and 5.2 cm of subsidence for the same time period. In the future, these rates could be refined through the use of more spatially-resolved data sources (e.g., InSAR) to complement the GPS data which is fairly sparse along the Central Coast. But, in general, even the highest rates of vertical motions that were recorded locally in the Santa Ynez mountains (Wehmiller et al. 1979) rarely exceeded more than 6 mm/yr, and therefore are quite small relative to the expected rates of SLR by the middle and end of the 21st century. Further, the recent launching of the Sentinel-1A (2014) and Sentinel-1B (2016) satellites equipped with advanced sensors will allow for a comprehensive assessment of vertical land motion rates across the region. This will enable vertical land motion to be more precisely integrated into coastal flood projections than has been done previously in Santa Barbara County (Barnard et al. 2014, OCOF 2018).

The National Research Council (2012) study projected 92 cm of SLR for San Francisco by 2100 (range 42-166 cm). More recent work incorporated advanced models and observations of ice sheets, suggesting the possibility of more extensive loss from Antarctica in the 21st century than previously considered (DeConto and Pollard, 2016), as well as a probabilistic approach to support risk assessment (Kopp et al. 2014). The new approaches were incorporated into the latest CA-focused SLR projections (Griggs et al. 2017) and California's Fourth Climate Assessment (Pierce et al. 2018), both of which suggest SLR by 2100 of up to ~3 m is physically tenable, though unlikely. Sweet et al. (2017) integrated this latest SLR science into continuous probabilistic projections across North America, including the Central Coast, and placed them in the context of a flood risk framework, with similar upper end SLR projections.

Median SLR projections have not changed markedly in recent years, and significant uncertainty remains in terms of the timing of SLR projections based in large part on uncertainty in emissions pathways. Nevertheless, research suggests that even with net zero future emissions, at least ~1 (Mengel et al. 2018) to 2 m of SLR is inevitable over the next few centuries. This is due to SLR response lag time with temperature, and current emission trajectories in the 21st century will commit the oceans to 9 m of SLR (Clark et al. 2016) with significant consequences for coastal communities.

TAKE-HOME MESSAGE:

- Historical sea level rise observations from tide gauges in the region have lagged behind the global average, but recently observed and projected acceleration poses a significant threat to coastal communities.
- Accelerating SLR combined with a lack of ample sediment in the system will continue to drive the landward erosion of beaches, effectively drowning them between the rising ocean and the backing cliffs and/or urban hardscape.

Floods

Patrick Barnard

COASTAL FLOODING

There has not been a continuous assessment of the Central Coast's flooding exposure to sea level rise since California's Second Climate Assessment (Heberger et al. 2011), but the Coastal Storm Modeling System (CoSMoS: Barnard et al. 2014) will have projections for this entire region in early 2019. The United States Geological Survey (USGS) developed CoSMoS, a unique, robust modeling approach to comprehensively assess the physical and socioeconomic impacts of climate change. CoSMoS translates model projections of the physical hazard exposure (e.g., flood extents) into public, web-based interactive maps that are used to support emergency response and local climate adaptation planning as well as evaluate socioeconomic exposure. CoSMoS expands and improves on earlier studies by dynamically modeling 40 storm and SLR scenarios across California, and incorporating fluvial discharge, ocean swell, storm surge, and sea level anomalies (as during El Niño). CoSMoS also presents the uncertainty of coastal flooding through an analysis of potential error in the model water level predictions, elevation data, and vertical land motion. CoSMoS has been completed for all of Southern California, including Santa Barbara County from the Ventura County line up to Pt. Conception, as part of California's Fourth Climate Assessment (O'Neill et al. 2018, Erikson et al. 2018).

CoSMoS results indicate serious concerns in the Santa Barbara region over the 21st century. The most vulnerable regions for future flooding across the region include Carpinteria, Santa Barbara Harbor/East Beach neighborhood, Goleta Slough/Santa Barbara Airport, Devereux Slough, and Gaviota State Park (Figure 12). Many beaches will narrow considerably, and two-thirds may be completely lost over the next century across the region (Vitousek et al. 2017). The further narrowing and/or loss of future beaches (and the ecosystems supported by those beaches) will primarily result from accelerating SLR combined with a lack of ample sediment in the system, which together will continue to drive the landward erosion of beaches, effectively drowning them between the rising ocean and the backing cliffs and/or urban hardscape.

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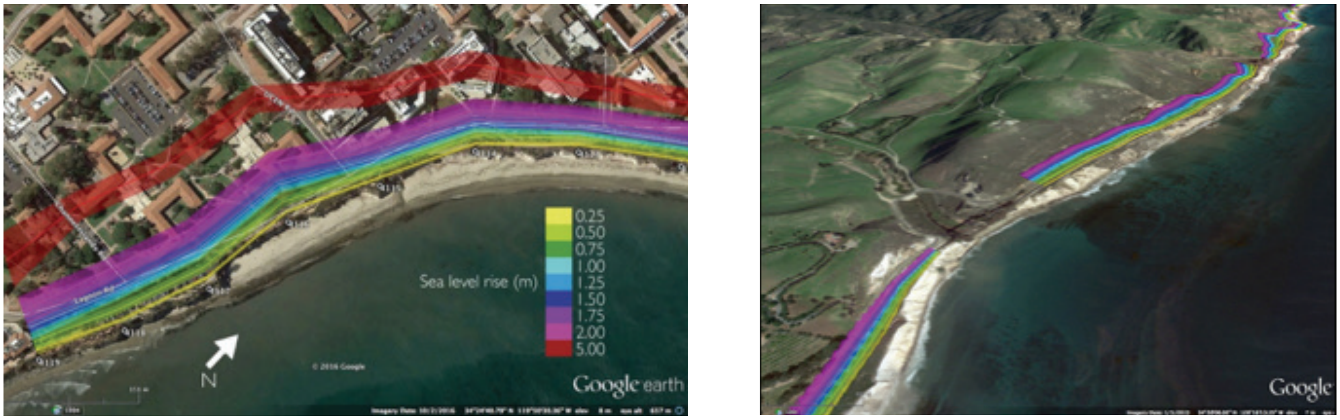
[9] CoSMoS results for Santa Barbara County are on the interactive Our Coast Our Future Web tool (www.ourcoastourfuture.org). Socioeconomic impacts are available from Hazards Exposure Reporting and Analytics (HERA) web tool . These sites will show projections for all of the Central Coast in 2019 https://www.usgs.gov/apps/hera/; Jones et al. 2016, 2017.

FIGURE 12

Examples of future flood hazards: Goleta (top left), Santa Barbara Harbor/East Beach (top right) and Carpinteria (bottom), showing the 1 m SLR scenario coupled with the 100-year coastal storm from CoSMoS projections.

The beaches along the UC Santa Barbara shoreline, for example, are almost completely devoid of dry sand at high tide following the 2015-16 El Niño (Barnard et al. 2017). This stresses existing sandy beach ecosystems and leaves the cliffs more vulnerable to wave attack, further placing cliff top ecosystems and structures at risk. Cliff retreat will also be a serious threat to sections of Highway 101 over the coming century, particularly in western portions toward Gaviota and Summerland, in addition to residential property in Isla Vista and the Mesa (Figure 13- cliffs) (Limber et al. 2018).

FIGURE 13: EXAMPLES OF PROJECTED CLIFF RETREAT UNDER A SERIES OF SLR SCENARIOS.



Left: Goleta County Beach and Campus Point. Right: Along the 101 corridor near Gaviota. Colored bands around the lines represent projection uncertainty for that sea level rise scenario. Projections from Limber et al., (2018).

For two meters of sea level rise combined with the 100-year storm event, CoSMoS projects the exposure of 11,780 residents and $2.4 billion in property across the most developed portion of Santa Barbara County. Across the region, Carpinteria is the most vulnerable city by population, with 4,615 residents at risk of flooding, with the City of Santa Barbara having 2,799 residents at risk. Unincorporated Santa Barbara has the most property value at risk, totaling $1.0 billion under the aforementioned scenario, with the City of Santa Barbara totaling $0.8 billion[9].

The Pacific Institute Report (Heberger et al. 2011) used decades-old FEMA base flood elevation predictions to map future flood exposure for the entire Central Coast region. Based on this data set, they predicted that 25,900 residents would be exposed to coastal flooding from 1.4 m of SLR combined with a 100 year-storm, with Monterey County (14,000 residents and $2.2 billion in property exposed) being the most vulnerable county. Another important coastal

flooding study covering the region includes coarse-scale inundation mapping from a 100-year storm and SLR on natural gas infrastructure (Radke et al. 2017). While the results vary across the different studies, due to the relatively low population density, the Central Coast is far less vulnerable to future coastal flooding compared to Southern California and San Francisco Bay. Nevertheless, there are still a number of low-lying coastal communities with locally-significant flood exposure risk, including Carpinteria, Santa Barbara, Pismo Beach, Avila Beach, Los Osos, Morro Bay, Monterey, Moss Landing, and Santa Cruz, among others.

COASTAL CHANGE

Long term (1800s-1998/2001) shoreline change across the region ranges from one of the highest long-term erosion rates in the state for Monterey Bay (-0.2 m/yr) to among the most accretionary, Morro Bay region (+0.1 m/yr). However, the sandy beaches of the entire Central Coast feature very high rates of erosion in the last several decades of the study (1950s/1970s-1998/2001), averaging -0.6 m/yr (Hapke et al. 2006). Coupled with accelerating rates of SLR over the coming decades, these rates can be expected to increase significantly.

TAKE HOME MESSAGE:

- Over the next century, projected flooding, erosion and cliff retreat hazards will threaten many Central Coast communities.

Long-term cliff retreat across the Central Coast averaged -0.3 m/yr from 1920s/1930-1988/2002, a total of 17.3 m of retreat, with a local maximum of 147.6 m of retreat at Pfeiffer Beach in Big Sur (Hapke et al. 2007). For 1 meter of sea level rise by 2100, rates of cliff retreat in Santa Barbara County are expected to increase by 55 percent (Erikson et al., 2018, Limber et al., 2018).

Individual coastal landslide events are challenging to predict, but the predictability of individual coastal slope failures is improving. One of largest coastal landslides ever observed occurred at Mud Creek along the Big Sur coastline in May 2017, following a season of exceptionally high rainfall. Following the destructive Thomas Fire in December 2017, a heavy rainfall event in January 2018 triggered major debris flows in Santa Barbara County, carrying large volumes of sediment to the coast in Montecito. The expected increase in wildfire occurrences over the next century due to warming temperatures, coupled with an increase in extreme precipitation events (Pierce et al. 2018), will lead to a correlative increase in debris flows. The Thomas Fire is discussed in greater detail in Section 5.

TSUNAMI HAZARDS

Though damaging tsunamis have occurred infrequently in California, they are a possibility that must be considered in coastal communities. It is possible that tsunami flooding hazards will increase with SLR. The Central Coast is most vulnerable to a tsunami generated by an earthquake along the Aleutian-Alaska megathrust.[10] Present-day inundation risk maps combining multiple tsunami generation sources have been produced by the California Geological Survey, http://www.conservation.ca.gov/cgs/geologic_hazards/Tsunami/Inundation_Maps/Pages/index.aspx

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[10] An oceanic trench along a convergent plate boundary which runs along the southern coastline of Alaska and the Aleutian islands.

COASTAL ADAPTATION

Numerous communities along the Central Coast are in the process of developing and implementing coastal hazard assessments and/or climate adaptation plans (see Section 4.2.3) to reduce the future impacts of these aforementioned coastal flooding, beach erosion. and cliff retreat projections. Adaptation options being considered include natural solutions such as vegetated dunes and beach nourishment. These options are discussed more thoroughly later in Section 3.4.

Wildfire and Post Wildfire Impacts

Christina (Naomi) Tague

WILDFIRE

Wildfire is a frequent occurrence within the Central Coast region. The last decade saw a series of dramatic fires, each with substantial impacts on ecosystems and human infrastructure. Several of the largest fires in California have occurred within the last 10 years including the Thomas Fire (Figure 14: see Section 5 for a case study of the Thomas Fire), the largest fire in California history with over 100,000 ha burned and more than 1000 structures lost.

The frequency and severity of fire and its impact within in the Central Coast is sensitive to climate variables and growing populations. The threat of fire to human populations increases with expansion of the wildland urban interface (WUI) (Mann et al. 2016). Proximity to WUI increases suppression but also ignitions and the human costs of fires and post-fire flooding.

FIGURE 14

Thomas Fire Photos: Mike Eliason, Santa Barbara County Fire Dept

Annual climatic water deficit, which measures water availability relative to water demand, is generally a strong predictor of fire occurrence and burned area in semi-arid regions, largely due to the correlation between annual water deficit and fuels and fuel moisture. Warmer temperatures will increase water demand and climate water deficit and thus fire risks. However, warmer temperatures do not have the dramatic impacts on fire season length and water availability that occur in the more snow-dominated regions of the state. Mann et al. (2016) assess the contributions of natural factors, including climate water deficit and human factors (such as distance to homes) to fire occurrence and found that the Central Coast, along with southwestern Sierra, showed the highest responses relative to other regions to both of these factors. Fire size in the Central Coast increases with both air temperature in the month of ignition and with low precipitation in the preceding 12 months (Potter et al. 2017).

Mediterranean type Ecosystems (MTE's) are situated on a transition zone where reductions in water availability can reduce fuel accumulation and thus decrease fire frequency (Batilori et al. 2013). Thus, a key factor in fire regimes for the Central coast will be precipitation patterns. Climate models differ in precipitation predictions for this part of California. Results are also likely to vary across the substantial precipitation gradient from south to north along the Central Coast. More northern higher precipitation areas may see decreased fire return intervals and higher severity, while areas to the south may ultimately see the opposite as warming increases climatic water deficit but also reduces vegetation growth rates and fuel loads.

Another important factor in fire size and severity in Central California is wind. Dry winds during Santa Ana, Sundowner, or Diablo events, which carry dry, warm air to the coast, play a key role in amplifying "fire weather" conditions. Santa Ana winds originate in the elevated Great Basin and blow southwestward (Hughes and Hall 2010). Santa Ana and Sundowner winds have fanned many of Southern California's most catastrophic wildfires (Westerling et al. 2004). In October 2017, a Diablo wind event contributed to fire that caused enormous damage in Sonoma and Napa Counties. Modelers are still working to determine how Santa Ana, Sundowner, and Diablo winds may respond to climate change. Some results suggest decreased activity based on a combination of observations and climate model projections (Hughes et al. 2011). However, there is no indication of decreased activity in the longest record of Santa Ana winds available (Guzman Morales et al. 2016). GCM simulations suggest that late season Santa Ana winds will continue to be most frequent in December and January, and that they will likely become hotter with climate change (Hughes et al. 2011)

Prediction of fire severity and frequency change in Central Coast is therefore challenging, particularly given uncertainty in climate predictions of precipitation and wind for this region and the high and complex sensitivity of fire regimes in MTEs (Mediterranean type Ecosystems) to precipitation and climatic water deficits. It is important to recognize, however, that the basic characterization of this system as one that is dominated by fire is unlikely to change, and it is highly likely that the Central Coast will continue to see large, severe fires. Consequently, growing populations and expansion into the WUI will increase vulnerability to fires and projected increases in precipitation intensity during storms may increase post-fire impacts.

POST FIRE IMPACTS

For the Central Coast, fires dramatically alter runoff production and streamflow. Paired catchment studies show that postfire annual streamflow increased between 82-200 percent in first post fire year, but increases varied strongly with annual precipitation in the year following fire (Bart, 2016). Both runoff production and sediment following fire

depend strongly on subsequent rain events (Valeron and Meizner 2010). High intensity events increase export while lower intensity (e.g. Hubbet et al. 2012 for post-Williams fire example) and growing season rain events stimulate post-fire regrowth and hasten post-fire hydrologic recovery. A sequence of high-intensity rainfall immediately after fire (such as what occurred following the Thomas Fire) or drought inhibition of vegetation recovery are both consistent with climate change projections and thus both may intensify fire effects in this region.

TAKE-HOME MESSAGE:

- Frequent and sometimes large wildfires will continue to be a major disturbance and expansion into the wildland urban interface will continue to increase risks to human communities
- Post-fire recovery time may be lengthened, and fire spread following ignitions will be enhanced, leading to a complex impact on fire regimes.

There is some evidence that increasing fire frequencies can cause coastal sage shrubs and chaparral to shift to grasses, including exotic grasses (Cox et al. 2014). A shift in ecosystems can have feedbacks on fire regimes since grass lands tend to promote more frequent fires (Keeley et al. 2005). Climate impacts, particularly precipitation, also alter post-fire behavior including the recovery trajectories and the rate of vegetation recovery following fire, although these effects vary with fire severity, pre-fire species, and landscape characteristics (e.g. soil and N-availability) (Keeley et al. 2005).

Nutrient fluxes are also elevated during post-fire periods. Nutrient fluxes from coastal watersheds in Central California affect nearshore marine and estuarine waters (Mertes and Warrick, 2001). As with sediment, these nutrient fluxes from coastal California occur largely as pulses during storm events (Homyak et al. 2014, Goodridge and Melack 2012). While fires consume biomass and thus release some of the associated nitrogen to the atmosphere, substantial N is also deposited as N-rich ash that may later be exported during rain events (Keeley and Rotheringham, 2001). Fires also remove vegetation and disrupt microbial processes that take up N. Consequently, post-fire runoff in this region typically has elevated N-concentrations (Mooney and Rundel 1979) and expected increases in rainfall intensity with climate warming may intensity this effect. Further, Hanan et al. (2016) show that higher post-fire N-export if fire is followed by drought that reduces rates of post-fire vegetation regrowth and uptake.

Sediment Transport and Deposition

Joel B. Sankey, Amy East, Jason Kreitler, Christina (Naomi) Tague

Sediment transport and deposition (sedimentation) occurs from natural and anthropogenic sources in rivers, lakes, and reservoirs. Substantial changes in sediment transport (such as a major increase or decrease in sediment supply) can impact aquatic ecosystems that depend on a particular sediment quantity and particle size, for example, through altering stream-channel geomorphology or fish habitat. For human communities that rely on surface water resources, sedimentation can impact water supply and quality. Sedimentation in reservoirs affects water supply by reducing the reservoir volume available to store water. Sediment, as well as the nutrients and chemicals adsorbed in sediment, can serve as pollutants that decrease water quality and make water treatment necessary and costly.

For California's Central Coast, sediment supply to stream channels occurs from overland flow across land surfaces, and on hillslopes from dry ravel processes and debris flows and landslides. The latter mass-wasting processes move large sediment quantities, particularly as a result of intense, long-duration winter storm rainfall. Sediment that enters rivers and streams is then transported toward estuaries and the coast, especially during winter storm events that greatly increase river discharge. The amount and type of vegetation on the landscape is one of many key controls on sediment supplies in the Central Coast region. Vegetation loss from wildfires can induce post-fire sediment transport by dry ravel in which particles travel individually down steep hillsides. Loss of vegetation after wildfire also exacerbates hillslope erosion due to excess rainfall and runoff, and mass wasting events like debris flows and landslides are common in such conditions (Gabet 2003, Gartner et al. 2004, 2008, Lamb et al. 2011, Warrick et al. 2012, 2015). Sediment eroded and deposited by recent events in 2017–2018, like the Thomas Fire and Montecito debris flows for example, have had devastating impacts on human lives and property, and have damaged infrastructure including water storage and treatment facilities. However, sediment-related natural disasters in Central Coast watersheds can also occur from landslides and debris flows even in the absence of fire during extreme wet years (e.g., Ellen and Wieczorek 1988).

The amount of sediment transported by individual Coastal California rivers (i.e., those that drain California's coastal mountain ranges and debouch directly to the Pacific Ocean, rather than draining to the Central Valley and San Francisco Bay) can vary widely from year to year and from decade to decade (Farnsworth and Milliman 2003, Warrick et al. 2015), and varies geographically from the drier southern part of the state to the much wetter coast of Northern California. Watershed lithology, topographic relief, and precipitation are important factors controlling the annual sediment load transported by these rivers. Many Coastal California rivers are managed for flow regulation, storage, or diversion, with dams and reservoirs that retain sediment in upstream portions of the watersheds substantially reducing the amount of sediment that would otherwise be delivered to the coastal river mouths each year (Inman and Jenkins 1999, Farnsworth and Milliman 2003, Willis and Griggs 2003, Andrews and Antweiler 2012).

Along California's Central Coast, annual sediment export from individual watersheds can vary by a factor of 500 or more between extreme dry and extreme wet years, even without any added influence of wildfire effects (Conaway et al., 2013; East et al., 2018). Most of the total sediment transported during multi-decadal time periods occurs in a small number of individual years associated with specific climatic conditions (Coats et al. 1985, Best and Griggs 1991, Andrews and Antweiler 2012, Gray et al. 2015). These climatic conditions are controlled in part, though not exclusively, by annual- to multi-decadal-scale climatic oscillations in the Pacific Ocean, namely the El Niño–Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO). Andrews and Antweiler (2012) reported that sediment fluxes in California's Central Coast rivers are relatively large during both El Niño and La Niña phases of the ENSO cycle, but they stated that "large annual sediment fluxes during an El Niño tend to occur in conjunction with a warm PDO phase, while large annual sediment fluxes during a La Niña tend to occur in conjunction with a cool-PDO phase."

However, although watershed sediment export on the Central Coast does generally correlate with the El Niño and PDO cycles, it is important to recognize that some extremely wet years with large storms and large quantities of sediment export on the Central Coast occur during neutral ENSO and PDO conditions. Two notable examples include a deadly January 1982 storm event that produced fatal landslides, debris flows, and flooding, and in some watersheds moved 20 percent of the sediment load for the decade (Griggs 1988, Ellen and Wieczorek 1988); and the record-wet winter of 2016–2017. During the 2016–2017 winter, an ENSO-neutral winter, an unprecedented series of major atmospheric-river, or "pineapple express" storms (Gershunov et al. 2017), which originate in tropical latitudes and carry large quantities of moisture due to the warmth of the air masses they move, caused repeated floods in Central Coast rivers with 2- to 30-year recurrence intervals. These storms generated watershed sediment export far above normal values, in part because the storms caused numerous landslides that served as new sediment sources (East et al.,2018). There is some indication that ENSO-neutral conditions may set up atmospheric circulation that facilitates the movement of atmospheric-river storms toward the West Coast (Bao et al. 2006); therefore, it is important to recognize that ENSO-neutral conditions may pose substantial risk for flooding, landslide, and debris-flow hazards on the California coast.

Following landscape disturbances such as wildfire or widespread regional landslides after an extremely wet winter, sediment yield from watersheds along the Central Coast is expected to remain elevated for 5–10 years (Keller 1997, Warrick et al. 2012). These elevated watershed sediment yields after landscape disturbance in turn reduce the amount of water-storage capacity in dammed Central Coast reservoirs (Smith et al. 2018). For watersheds that drain directly to the Pacific Ocean, substantial inter-annual fluctuations in watershed sediment yield affect coastal sediment delivery and coastal landforms such as river-mouth sandbars and beaches, with associated coastal sediment-management implications. The substantial (e.g., order-of-magnitude) increase in sediment delivery to the coast that occurs during a very wet year (Barnard and Warrick 2010, East et al. 2018) might increase the need for dredging to maintain navigable harbors and river mouths. Large sediment inputs from coastal rivers also could potentially affect ecosystem health in the nearshore zone (Conaway et al. 2013). However, because coastal streams supply 70–85 percent of beach-sized sediment along the California coast (Griggs 1987), the additional sediment load from rivers in such wet years may reduce the need for artificial beach nourishment.

Projections of future climate scenarios indicate that winter atmospheric-river storm activity is likely to increase along the West Coast (Flint and Flint 2012, Russo et al. 2013, Warner et al. 2015, Swain et al. 2018). This implies that such winter storms that produce abnormally high sediment export are likely to occur with greater intensity in the future, although interspersed with very dry years (Swain et al., 2018). Changes in vegetation and fire regimes are less certain for the Central Coast region, but fire frequency, size, and severity may increase for the more northern parts of the Central Coast, potentially adding to the likelihood of increased sediment flux (Sankey et al., 2017). The entire Central Coast, however, will continue to be at risk for large, intense fires and thus as precipitation extremes increase, the probability also increases that an intense rain event will follow soon after a fire, leading to catastrophic events such as the debris flows in Montecito following the recent Thomas Fire.

TAKE-HOME MESSAGE

- Sedimentation varies widely in individual watersheds and rivers due to inter-annual hydro-climatological variability. It is exacerbated by landscape disturbances (e.g. wildfires or landsliding) and can remain elevated for years.

Central Coast Natural Resource Systems Science

This section examines the science for the natural resource systems that comprise the dominant land cover (over 75 percent) for the Central Coast Region, along with potential climate impacts to the difference ecosystems.

The Central Coast is an area of high biodiversity characterized by a mosaic of redwood forests, mixed evergreen forests, coastal scrub lands, and grasslands or "coastal prairies." Areas in the Santa Cruz Mountains contain numerous endemic, federally-listed, and sensitive species (CNPS 2018, Marangio and Morgan 1987) in a spatially narrow distribution band that could be highly vulnerable to climate change (Conservation International 2018). Narrow beaches dominate the coastline, and there are fragments of coastal wetlands, dunes, coastal strand plant communities, and small pockets of rocky intertidal zone.

Plants

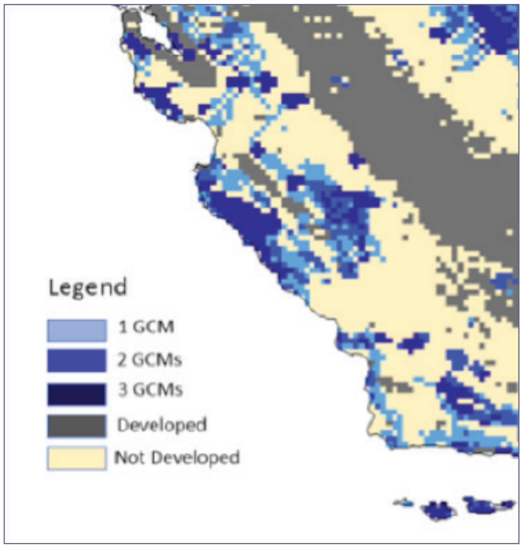
NATIVE PLANTS

Lee Hannah

California's native plants provide habitat for the state's diverse and unique assemblages of animals. These plants are unique in their own right, making California the largest part of one of the world's floristic provinces (the California Floristic Province - CFP) and a biodiversity hotspot. California has over 2,000 plant species that are found nowhere else in the world. The range of suitable habitat for each of these plants will shift with climate change depending on unique climatic tolerances; thus, ecosystems and habitats will lose and gain species. In mountain ranges, plant species will shift upslope to track warming temperatures. In the lowlands, species will move north.

In the Central Coast, vegetation will be rearranged by climate change, altering the habitats of wildlife. Among the changes of greatest concern are shifts in plants found nowhere else in the world (Central Coast endemics) or found only in the Central Coast and other parts of California (California endemics). Models of species' ranges can be used to estimate the movements of Central Coast plants. These models use species' present locations to estimate the climatic conditions in which the species can survive. As

FIGURE 15



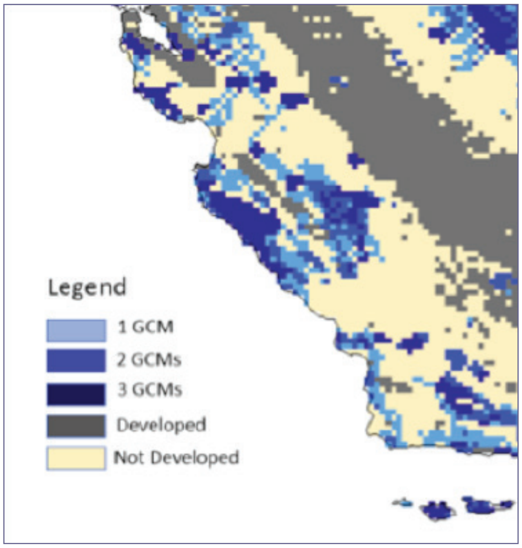
Hotspots of species for connecting current and future ranges. Darker blue indicate more species chains of suitable climate from present to future climate changes, the models simulate the movement of the species to track suitable climate. To conserve species as these changes in location are unfolding, it is important to protect species where they are now, where they will be in the future, and to know the connecting paths that can get them from where they are now to where they will be. These 'chains' of habitat link present conditions to similar suitable conditions in the future. Solving this for thousands of species is complex, and computers are used to find solutions. Figure 15 is one example is for the Central Coast.

Areas with several 'chains' are shown in shades of blue - the darker the blue, the more agreement among climate models. The darker blue areas represent places where many species find suitable chains and these priorities are robust to differences between climate models. These are high priority areas for managing native plant transitions. Each of these areas have some anchoring conservation areas, but these are small in comparison to the overall extent of the priority areas.

The Central Coast has several high priority areas for native plant range movements, including Big Sur, Santa Cruz, Gaviota, the mountains of Morro Bay/San Luis Obispo (SLO), Pinnacles south, Santa Ynez mountains, and Point Conception. Some of these areas correspond to well-protected landscapes, while some are in landscapes that may warrant additional protection to better conserve their native plant communities as climate changes.

The species driving these priority areas are diverse. 55 species in Morro Bay/SLO, 54 species in Big Sur, 43 in Gaviota, 40 in Santa Cruz, 33 in Pt. Conception, 28 in Santa Ynez, and 21 in the Pinnacles, with all species finding unique pathways that help them move in response to climate change. The conservation status of these areas is diverse as well, ranging from very well conserved areas to areas in which there are few conservation lands. Figure 16 illustrates the priority areas with protected lands overlaid (in green).

FIGURE 16



Category 1 & 2 protected areas (green) are overlain on plant climate change priority areas

FIGURE 17

Big Sur – near Julia Burns SP Photo: Joseph Plotz - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=10656495

The Big Sur area (Figure 17) corresponds to a well-protected landscape encompassing National Forest and other conservation lands. Some important plant climate change priorities to the south of the main block of protection remain unconserved however. Strategic augmentation of protected lands could help improve the climate resilience of this area.

TAKE HOME MESSAGE

- Prioritizing noted protected areas for conservation and managing those lands to retain substantial areas in natural condition will facilitate movements of the Central Coast's native plants in response to climate change.
- The unique topography and climate of the Central Coast make it a special place to conserve hundreds of species as climate changes.

The Santa Ynez mountains priority areas are almost all within the Los Padres National Forest, making land use compatible with climate adaptation possible. The Point Conception area is relatively well protected by Vandenberg Air Base and the new Nature Conservancy Bixby Ranch acquisition. Managing these two parcels together may be key in helping rare native plants adapt to climate change.

Gaviota has relatively small state parks and private protected lands, with most of the rest of the area not under formal protection. However, the ranch lands of this coast are compatible with native plant movements in response to climate change. Santa Cruz, Gaviota, Pinnacles, and the mountains of Morro Bay/SLO are less well conserved. Each of these areas has some small anchoring conservation areas. Pinnacles itself is protected, but the main plant priority area is in the mountains and hills south of Pinnacles, which is almost completely unprotected.

The mountains of Santa Cruz and Morro Bay/SLO present complex mosaics of urban and wildlands, little of which is conserved on a scale meaningful for plant responses to climate change. All of these areas are high priority for additional protection to facilitate native plant movements to climate change.

COASTAL SHRUBS

Laurel Fox

Chaparral and coastal sage scrub (CSS) communities are both dominated by low shrubs that are sometimes also mixed with grasslands and/or oak woodlands. Both types of shrub communities reflect ecological and evolutionary responses to fires, often linked to the hot, dry summers when fires typically start. Additionally, the composition and diversity of ecological communities along the California coast are linked to the summer marine layer of fog and low clouds, which drive adaptations, and to biotic interactions. Chaparral shrubs in general are more drought tolerant.

Chaparral

Chaparral is the dominant vegetation type in the California floristic province (Dennison and Moritz 2009, Keeley et al. 2011, Halsey and Keeley 2016), with by far most of California's biodiversity and endemic species (Harrison 2013). Summer fog provides additional water and milder summer temperatures, and consequently, longer intervals between natural fires (100-150 years) for coastal chaparral than for further inland vegetation (Greenlee and Langenheim 1980, 1990, Vasey et al. 2014). Most of the biodiversity in chaparral habitats consists of rare species with restricted ranges, particularly herbaceous annuals (Harrison 2013, Keeley and Davis 2007).

Chaparral, a fire-dependent evergreen shrubland vegetation, has moved progressively northwards as the state became drier over thousands of years (Harrison 2013, Hufnagel and Garamvolgyi 2014, Anderson et al. 2015). Human ignitions, fire suppression, and short-term meteorological events have dominated variability in fire activity in chaparral zones in recent decades (Abatzoglou et al. 2016, Mann et al. 2016). However, fire area and frequency across California's Mediterranean biome, and across chaparral specifically (e.g., Dennison & Moritz 2009; Dennison et al. 2014), have not increased over the past few decades despite increased aridity (Williams et al. 2016), though the influence of the 2012-2016 extreme drought in California is not yet well known.

Along the Central Coast, chaparral is mostly 'maritime' chaparral vegetation dominated by species of Manzanita that occur variably as stands within or near coast live oak or closed-cone conifer forests (Van Dyke et al. 2001, Griffin 1978) (Figure 18). Some manzanitas are state listed as a species of concern whose abundances reflect complex interactions of climate and biotic interactions, particularly herbivory. Deer browse reduces growth, reproduction, and survival in ceanothus. However, because plants protected from deer browse grew more, they were actually more water stressed than control plants during the recent drought (Pittermann et al. 2014, Koch and Fox 2017). Conversely, as the abundances of deer and other wildlife declined during the drought (e.g., McKee et al. 2015), previously browsed shrubs grew and reproduced well and then responded rapidly to the two wet years since (Fox, unpub). These observations suggest that unless deer populations increase again between droughts, or in areas without much deer browse, ceanothus shrubs are likely to grow rapidly, but will become vulnerable with further droughts projected under climate change.

FIGURE 18

Montane chaparral and woodlands in the Santa Ynez Mountains, near Santa Barbara, California. Photo: Wikipedia (https://en.wikipedia.org/wiki/California_chaparral_and_woodlands)

Patches of chaparral vegetation ('sand chaparral') also occur in isolated Sandhill habitats in the Santa Cruz mountains, with reduced maritime influence and higher winter precipitation ('transitional chaparral,' *sensu,* Vasey et al. 2014), and there are also patches of inland chaparral (Griffin 1978, Van Dyke et al. 2001, Vasey et al. 2014). Many shrubs and herbaceous species in maritime chaparral and sand chaparral are state or federally listed as threatened or endangered.

For annual plants, demographic rates (e.g., survival, reproduction) are lower in dry years than in wetter years (Fox et al. 2006). As dry years become more common, population growth rates of these annuals will become marginal and populations are likely to become locally extinct. However, browsing on these annuals, particularly by deer, rabbits, and woodrats reduces population growth even more than drought in some species, but not others (Fox 2007).

Over the entire community, plants in sandhill chaparral both initiated and ended flowering significantly earlier in 2011-2015 compared to their timing in the 1990s (Oshiro & Fox in prep.). South of Monterey and somewhat inland, about half of the chaparral sites showed severe stress (Potter 2015, from Landsat Images) in the recent state-wide drought, as did most grasslands. Forests did not appear to be as stressed. Coastal chaparral and forest sites might have had lower drought impact due to fog.

Coastal Sage Scrub

Coastal sage scrub (CSS) communities along the coast share some species with coastal chaparral but tend to be dominated by shrubs that are more drought deciduous, particularly sages in the genera *Artemisia* and *Salvia*; there are also many rare species found in CSS communities as well (Cleland et al. 2016). CSS are fire-dominated communities, but fire return intervals tend to be shorter than in nearby chaparral (Cleland et al. 2016). Invasive species have become more common in CSS communities and compete with native CSS species; CSS habitats may convert to grasslands after fires, grazing, or nitrogen deposition. Native plant cover and biodiversity in CSS communities have also been reduced due to introduced, commercial cultivars of *Pinus radiata* from New Zealand; these cultivars are expanding into CSS vegetation where they have been introduced to the north of *Pinus radiata*'s native distribution along the Central Coast (Steers et al. 2013).

The responses of plants to climate change, including precipitation, depends on the climates in which populations evolved. Central coast sites have higher rainfall, with historically less interannual variability in rain than in Southern California. Populations of the California Sagebrush, *Artemisia californica*, showed local adaptation across sites from Central to Southern California (Pratt and Mooney 2013); plants from more northern sites along the Central California coast had higher water use efficiency but lower growth rates than those from Southern California. Plants from the Central Coast flowered earlier, did not respond to added water, and had more genetic variation in plant growth and flowering in response to rainfall than those from the South. Southern plants, in contrast, had higher plasticity in growth and flower production with more water, were better defended and had faster growth rates than the northern populations.

TAKE HOME MESSAGE:

- Species responses to climate show marked geographical differences and depend on the climate in which the population evolved.
- Coastal scrublands resilience depends on joint climate effects, physiological responses that are modified by biotic interactions, and the extent of anthropogenic land use.

While climate change is projected to affect CSS communities, anthropogenic land use changes are likely to be stronger (Riordan and Rundel 2014). Because of climate change, CSS habitats along the Central Coast might expand where land use changes are not extensive. In contrast, CSS communities along the Southern California coast are likely to contract as climate change continues because loss of habitat coincides with increased anthropogenic land conversion.

GRASSLANDS

Madeline Nolan, Carla D'Antonio

The Central Coastal region contains many grassland alliances[11] (Keeler-Wolf et al. 2007) divided here into two main types: coastal prairie grasslands and inland grasslands (Heady 1992, Bartolome et al. 2007), which are likely to respond differently to climate change The former contains a strong representation of perennial grasses and forbs (herbaceous flowering plants) and is restricted to the immediate coast. The latter typically contains sparse if any native perennial grasses and is dominated by annual forbs and exotic annual grasses (Jackson and Bartolome 2002). The perennial species in the wetter climate of the coast maintain higher biomass are active over a longer period of the year, whereas the native and non-native annual species in the drier inland areas thrive in the more erratic and generally lower moisture regimes.

While native grassland alliances likely occurred throughout the region, centuries of human disturbance, particularly crop agriculture, left many grasslands with low native diversity and devoid of native perennial grasses (Stromberg and Griffin 1996). Such sites, considered semi-natural grasslands, are almost entirely exotic-annual dominated. Climate changes projections forecast for a warm/dry scenario in some interior regions and rain events that have shifted somewhat earlier with longer intervals between rain events; it is likely that habitats supporting inland type grasslands will be impacted. The immediate coast will likely experience less climate change due to the buffering effect of the ocean.

While the duration and intensity of annual droughts in California varies substantially with elevation, latitude, distance to coast, and local soil characteristics (Wu et al. 2010), high inter-annual variability in the amount and timing of rainfall is the norm. This suggests that most grassland species should be adapted to tolerate climate extremes and variability. Native perennial grasses, for example, concentrate their growth during wet winter months as an adaptation to the annual summer drought (Ehleringer and Mooney 1983, Vaughn et al. 2011), and some can survive prolonged droughts in a non-green state and then regenerate after it rains (Hamilton et al. 2002, Potter 2015). Others, particularly in coastal prairie grasslands, derive significant amounts of water from summer fog (Corbin et al. 2005) suggesting that their persistence may be threatened with climate change if summer fog declines. By contrast, inland grasslands do not receive summer fog (Torregrosa et al. 2016) or experience more extreme or prolonged droughts, a fact reflected the in greater domination by annual species and the occasional drought tolerant perennial.

California is known for its spectacular diversity of annual wildflowers, more than 1000 of which occur within grassland settings across the state (Schiffman 2007) (Figure 19).

FIGURE 19

Carrizo Plain National Monument (photo: Bob Wick, BLM)

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[11] A group of floristically related associations that collectively occupy a larger range than does any single association.

While there is geographic and edaphic variation in which forbs are present (Schiffman 2007), in any given year forb occurrence is related to both the timing and amount of rainfall, and the cover and dominance of European annual grasses (Pitt and Heady 1978). Molinari (2014) found that less precipitation and drier soils resulted in decreased diversity of native and non-native species, particularly for forbs in Northern Santa Barbara County.

How future changes in precipitation and drought will impact grasslands in the Central Coast will be dependent on 1) the proximity to coast, 2) the relative proportion of native to exotic, and perennial to annual species, and 3) the species pool of forbs. It is likely that valley grassland habitat in the Central Coast region will be more affected by climate change but will remain exotic grass dominated. This agrees with climate models that have explored how vegetation distributions could change in California with global climate change (Lenihan et al. 2003, Lenihan et al. 2008), with an increase in precipitation expected to reduce interior grasslands (replaced by woody species) and a reduction in precipitation predicted to increase the extent of grasslands because annual grasses are more adapted to fluctuating and often low rainfall. Therefore, the valley-type grasslands could see an expansion of the proportion of exotic annual grasses at the expense of native forb species, even if some exotic grasses have reduced seed production with shorter growing seasons. For the grasslands on the coast, however, future expansions or contractions are likely dependent on how the occurrence of fog changes with global climate change.

While it is likely that climate change will negatively impact native grasslands, restoration can be used to help mitigate the effects grasslands may face due to climate change. In fact, many practitioners have already begun to anticipate climate change in restoration planning. The most common way has been creating diverse seed pools (Bradshaw 1987, Montalvo et al. 1997) which target genotypes that are predicted to be adapted to future climate scenarios (Broadhurst et al. 2008, Beierkuhnlein et al. 2011, Hodgins and Moore 2016). Increasing the genetic diversity of a population is important as there is a well-known correlation between genetic diversity and population persistence in the face of environmental stochasticity (Montalvo et al. 1997, Gustafson et al. 2004). Another restoration technique that has been employed is controlled grazing. Grazing can be used to enhance native grass and forb occurrence, at the expense of exotic species (Huntsinger et al. 2007, Stahlheber and D'Antonio 2013) which can also help mitigate climate impacts on forb diversity. Therefore, while climate change is likely to change both the distribution and composition of native grasslands in the Central Coast there are concrete steps that managers to can take to help mitigate the negative impacts of climate change in the future.

TAKE HOME MESSAGE:

- Grassland communities will likely tolerate the extreme events projected under climate change. Specific effects will depend on proximity to the coast and the relative proportion of native to exotic, and perennial to annual species, as well as the species pool of forbs.
- Active management and restoration of communities that are known to be more tolerant of droughts can support adaptation.

FORESTS

Michael Loik

Central Coast forests - coastal and blue oak woodlands, montane hardwoods and conifer forests, redwoods, and foothill pines - comprise 21 percent of the region by area. The distribution of forest types is generated from a variety of physical factors such as aspect, slope, soil properties (chemistry, porosity), proximity to the coast, and frequency of fog (Callaway and Davis 1993). They include the world famous massive coast redwoods (*Sequoia sempervirens*) (Figure 20), which are some of the world's tallest trees. Redwood forests occur no more than about 70 km from the coastline, corresponding to the inland extent of summer fog advection (Johnstone and Dawson 2010). Air temperatures rarely go below 0°C in winter, and in summer daily maxima average 27°C from July - September. During this time of year, fog water supplies are crucial in the absence of rain (Dawson 1998). Redwood forests rely on summer fog, and evidence shows increased water stress for redwoods due to recent changes in fog frequency (Johnstone and Dawson 2010). Redwood forests typically occur over shale parent material (Noss 1999), which tends to produce soils that retain water. Their canopy structure determines variation in the understory environment, and as a consequence redwood forests harbor considerable diversity of arthropods and birds (Brand and George 2001, Willett 2001). The ongoing decline in coastal summer fog remains a challenge, requiring concerted physical and biological monitoring at multiple sites as climate continues to change.

FIGURE 20

Redwood forests on a north-facing slope and lower drainage, with a lone Douglas Fir tree in chaparral- the fog bank in the distance over the Pacific Ocean. February 2018, San Mateo County. Source: Michael E. Loik

One of the hallmarks of the Central Coast region is the multitude of microclimates created by topography, aspect, slope, and proximity to the Pacific Ocean. In addition to the importance for biodiversity, one consequence of this physical diversity is rapid spatial transitions between forest types, and between forests, chaparral, and grasslands. Coarse or highly-drained rocky or sandy soils neighboring redwoods forests are dominated by Douglas fir-tanoak, closed-cone pine, hardwood forests, or chaparral (Barbour 1993). Sandstones from the Miocene have created sand islands in the Santa Cruz Mountains that harbor numerous sensitive species (Marangio & Morgan 1987). The sensitivity of such abrupt ecotones to climate change are not well understood, but should be a priority for monitoring.

Historic land use has affected the extent and cover of Central Coast forests. Redwood forests were heavily logged for building materials and fuel for curing lime and manufacturing blasting powder. Following the 1906 San Francisco earthquake, redwood forests were widely harvested for rebuilding efforts. As a consequence, the impressive stands of redwood we see today are made of fossil fuel carbon captured in re-sprouted trees grown since clear-cutting in the 1800s and early 1900s. Based on live above ground biomass collected by the California Air Resources Board, similar

to all regions of California, the forests and wildlands of the Central Coast region lost about 10 percent of terrestrial carbon mass between 2000 and 2012, mostly between 2008-2010. This is in contrast to small increases in terrestrial live biomass for agricultural and urban portions.

Climate change impacts on physical conditions in Central Coast forests will interact with biotic factors such as insect and disease outbreaks. In recent decades, Sudden Oak Death has affected coast live oak, canyon live oak, California black oak, Shreve oak, and the closely related tanoak. The disease is highly problematic for forest health, fire risk, and property values in the northern Central Coast, including Monterrey and Santa Cruz counties (Rizzo and Garbelotto 2003). During wet weather, sporangia of the oomycete *Phytophthora ramorum* are produced on infected leaves, which can be dispersed by wind or via transported soil to infect new hosts. Epidemiological models of *P. ramorum* spread suggest broad scale movement into California's North Coast by 2030, but less toward the southern portions of the Central Coast because of drier conditions there. Some wetter climate scenarios for California in 2030 include wider spatial infection by *P. ramorum* across California (Meentenmeyer et al. 2011).

TAKE HOME MESSAGE:

- Microclimate and soils create abrupt ecotones (transitions) between forests, grasslands, and chaparral in the Central Coast region. The sensitivity of these ecotones to climate change are largely unknown.
- Changes in the timing and extent of coastal fog could be as important for Central Coast forests as broad-scale increasing temperatures and changing winter precipitation patterns.

The outcomes of climate change for fitness, productivity, and community structure in Central Coast forests will depend largely on how multiple abiotic drivers (increased air temperatures, altered fog patterns, changes in winter precipitation), and biotic factors (invasive species and insect and pest outbreaks) play out. It is likely that some species will increase in numbers or expand in range in response to climate change, whereas other species will decline. Central coast adaptation measures will require better monitoring and modeling of populations to determine best practices for stewardship (e.g. assisted migration) to promote desirable outcomes in a future climate.

Wildlife

Climate change impacts terrestrial ecosystems and wildlife in multiple ways, including invasion by exotic species, prevalence of wildlife disease, and loss of native habitats. Many species have undergone reduction of their geographical range and become highly vulnerable to extinction. Further, some species have moved towards either high latitudes or high altitudes in response to climate change, while other species have failed to reestablish their habitat associations. Phenological responses can differ among different species in the same ecosystem, ultimately causing disintegration of ecosystem components (Surasinghe 2011). This section discusses the impacts of climate change on Central Coast herpetofauna (amphibians and reptiles) as reflecting these responses to climate change.

CLIMATE CHANGE AND HERPETOFAUNA

Barry Sinervo

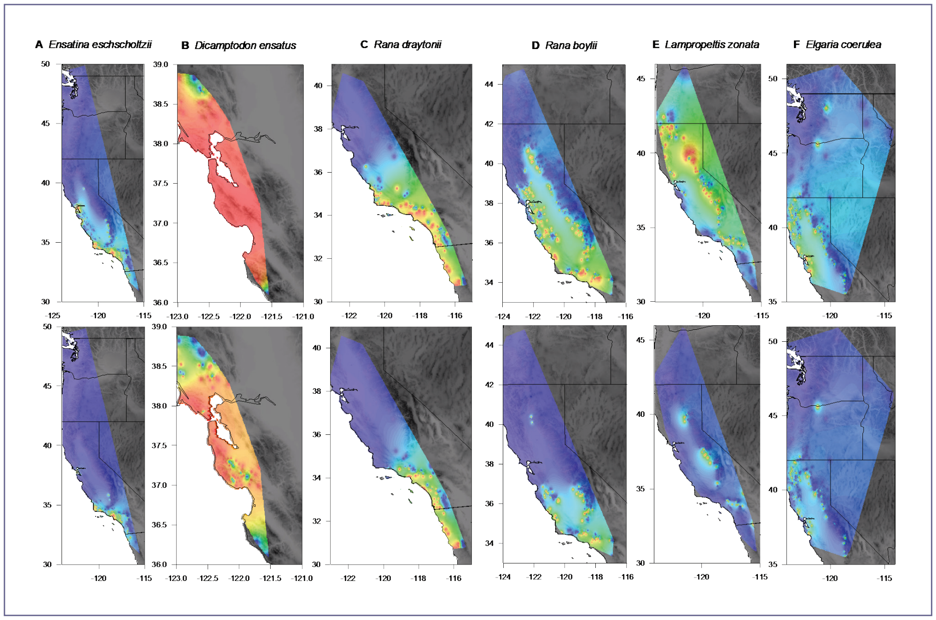
Biogeographic Patterns of Extinctions

Relatively high levels of amphibian and reptilian diversity contribute to the significant biodiversity in the Central Coast Region. This is where many amphibian species reach their southern range limit, and reptilian species with desert affinities reach their northern range limit (Tershy et al. 2016). An eco-physiological model was used over two decades (Sinervo et al. 2010, Caetano et al. 2017) to compute extinction risk of taxa.

The model detected extirpations of populations in the Central Coast and Bay Area including: the woodland salamander – *Ensatina eschscholtzii*, the pacific giant salamander – *Dicamptodon ensatus,* yellow and red-legged frogs – *Rana boylii* and *Rana draytonii* respectively, and the northern alligator lizard – *Elgaria coerulea*, which is live-bearing and thus at heightened risk of extinction (Sinervo et al. 2010) (Figure 21).

One clear pattern is that there are robust climate refugia at high elevations of the Santa Cruz and Santa Lucia Mountains (Figure 17). Similar analyses defined potential climate refugia that might be developed into protected lands such as the Santa Lucia Mountains (Sinervo et al. 2018). Under an RCP 4.5 scenario, all of the above species would benefit and most have large refugia along the Central Coast, likely because of the proximity to the ocean, which lowers air temperatures, as well as fog that has attenuated climate warming during the summer months (see climate and fog section). *Dicamptodon ensatus* is predicted to be extirpated from all sites under and RCP 8.5 scenario but might persist in the Santa Cruz Mountains under an RCP 4.5 scenario.

FIGURE 21



(A-F) Biogeographic patterns of extinction risk: refugia in the Santa Cruz and Santa Lucia Mountains Persistence (blue) vs. extinction probability (red) to 2070 under an RCP 8.5 scenario (top row) vs. RCP 4.5 scenario (bottom row) in 6 species of reptiles or amphibians.

Observed Extirpations during Surveys (1997-2017) of the Central Coast Herpetofauna

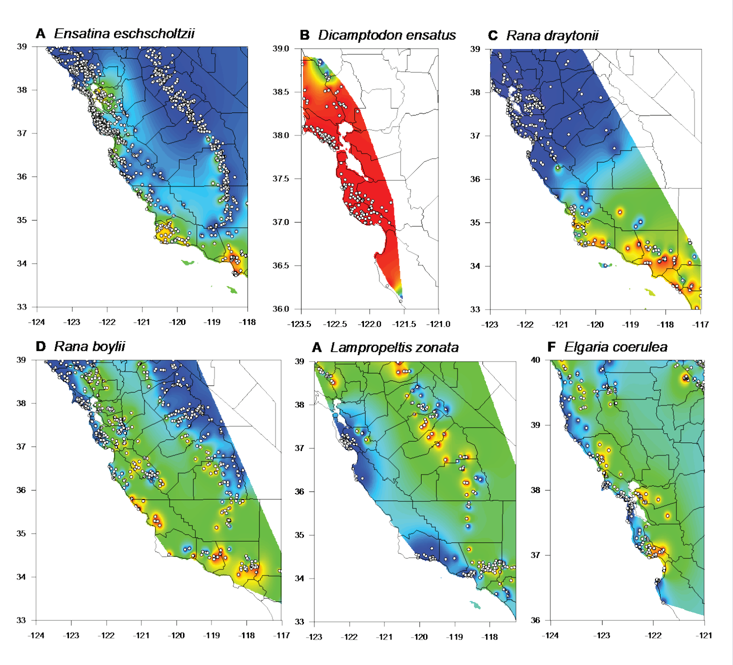
Surveys of herpetofauna of the Central Coast Region observed the occurrence of all species registered for the region (Stebbins, 2003). An example of the protective effects of the Santa Cruz Mountains and nearby coastal regions on the species range of montane taxa is seen in the California Mountain Kingsnake, *L. zonata*. In Santa Cruz County, it is often found at sites near sea level (50 meters, Aptos, CA, 200 meters, UC Santa Cruz, CA) as well as at the highest elevations of the Santa Cruz Mountains (Summit Road, Loma Prieta Peak). This snake is considered a montane specialist and is restricted to mountain peaks in the San Francisco Bay Area (Mt. Hamilton, Mt. Diablo, Mt. Saint Helena) and elsewhere in California. However, in Santa Cruz and Monterey County it occurs at sites besides the ocean.

Corridors of riparian habitat in urban areas allow herpetofauna to migrate from Coastal Protected Areas (e.g. State Parks) to higher elevations with largely intact habitat. The cooling effect of the ocean ameliorates climate impacts on biodiversity. Expansion of protected areas in riparian corridors and the mountainous regions of Santa Cruz will serve to maintain connectivity of populations near the ocean and on mountaintops, enhancing protection from climate warming (Sinervo et al. submitted, 2018).

The lizard *Elgaria coerulea* used to occur on Año Nuevo Island (vertnet.org, Dan Costa, pers. comm.), and still occurs on the mainland at Año Nuevo State Park. During a series of recent droughts when plant cover disappeared, it went extinct on the island. Plant cover provides a powerful ameliorating effect on herpetofauna because it lowers the temperatures that they experience. The conservation organization Oikos has been restoring habitat on the island and, if their efforts prove successful, the lizard could be reintroduced back to the island using source populations from the mainland. This lizard now only persists in heavily forested regions of the Central Coast, where the impacts of climate warming are ameliorated (Sinervo et al. submitted). It has also been disappearing from other Santa Cruz sites, and is being replaced by its egg-laying congener, *E. multicarinata*, which is benefiting from warming temperatures.

Reduced fog from Central Coast regions (Johnstone and Dawson 2010) has contributed to warming at *E. coerulea* sites beyond its eco-physiological limits (Sinervo and Schoenig, in prep). Where fog has attenuated most rapidly from high-elevation sites in the Santa Cruz Mountains it is already registered as extirpated (Figure 22). *Aneides lagubris*, the arboreal salamander, also used to occur on Año

FIGURE 22



(A-F) Persistence (blue) vs. extinction (red) to 2070 under an RCP 8.5

Nuevo Island (vertnet.org) and recent resurveys (2008-present) indicate it is also extinct. This salamander could be translocated to Año Nuevo Island from mainland parts of Año Nuevo State Park, where it still persists. More studies on hydric eco-physiology in tandem with vegetation cover are required to assess risk of extinction, particularly for amphibians.

Vegetation Cover and Extinctions

New experiments on vegetation cover indicate complex effects of tree cover at aquatic breeding sites of amphibians. For example, *R. draytonii* , the California red-legged frog, is listed as a federally endangered species (Shaffer et al. 2004), which breeds at the Arboretum pond at UCSC. Willows shade the pond and limit the ability of the frog to thermoregulate to its optimum temperature. Recent willow removal from 1/8th of the south margin of the pond has enhanced the ability of frogs to thermoregulate from a Te of 18°C in shaded areas of the pond to 25°C in the sites with sun exposure. Thus, restoration of amphibian breeding sites will require retaining vegetation such as willows, while also removing willows from some areas such that the amphibians can thermoregulate to achieve both suitable retreat sites from climate warming as well as optimum temperatures. Such studies on the hydric limits of eco-physiology are underway using operative hydric models to measure the water loss rates of amphibians at historic sites where we have detected extirpations, and at sites where the amphibians still persist. The overall pattern of extirpations implicates contemporary climate change as the ultimate cause. However, it will be important to assess other factors such as disease (Rohr and Raffael 2010, Rohr et al. 2008b), and pesticide and herbicide contamination (Rohr et al. 2008a) as factors driving extirpations.

Effects of Drought

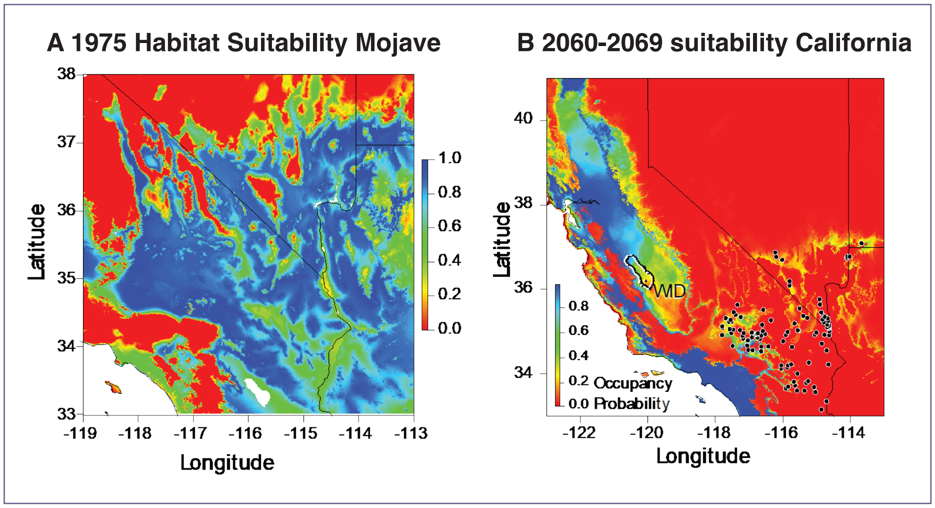
The importance of recent drought effects is drawn from an endangered lizard adjacent to the Central Coast Region in the Central Valley (and with historic records in the Salinas Valley), the blunt nosed leopard lizard, *Gambelia sila*, and from an endangered amphibian species that is endemic to the Central Coast, the Santa Cruz long-toed salamander, *Ambystoma macrodactylum croceum*. Westphal et al. (2016) found that the 2012-2016 drought severely limited reproduction of adult G. sila, which in turn limited recruitment of juveniles from nearly all sites where the species is found. The drought (Griffin and Anchukaitis 2014) also dramatically limited the migration and breeding of *A. m. croceum* in ponds in Aptos, CA (Laabs 2002, Allaback and Laabs 2013 surveys, 2017 underway), as have other historic droughts such as the 1987-1992 drought (Reed 1978, 1979; Ruth 1998). There is current monitoring of water-loss rates and Te of breeding ponds of *A. m. croceum*, and nearby forested habitat where adults retreat to aestivate (go dormant), with the goal of developing even more fine-scale models of extinction risk based on habitat preferences (Sinervo et al. in preparation).

The 2012-2016 drought impacted reptiles and amphibians at the landscape scale (e.g. the woodland salamander, *E. eschscholtzii*). During 2017 surveys in the eastern margin of the Santa Cruz Mountains, potential local extirpations (no salamanders found at Crystal Springs Reservoir, Santa Clara County Park) were registered. These re-surveys are in the exact location of projected future extinctions and thus may serve as a harbinger of the impacts of drought on herpet0fauna of California and the Central Coast Region in the future.

Expansion of Southern Deserts to the Central Coast

The Coastal Region is where the desert fauna reach their northern limits. Regional Climate Models (Salazar et al. 2011, Sinervo et al. submitted) suggest that valley regions of the Central Coast will desertify to the point where the California Desert Tortoise, *Gopherus agassizii*, could be translocated to regions around Santa Cruz, the Salinas Valley, as well as the Bay Area and near Sacramento. Suitable Mojave-like climate are projected to form by 2070 (Sinervo et al. submitted). Therefore, endangered species from the Central Valley, e.g. the blunt-nosed leopard lizard, might be translocated from the Central Valley to the Salinas Valley where they might thrive under future climates (Figure 23).

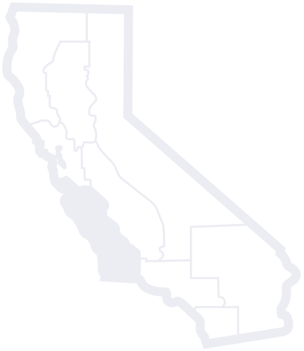
FIGURE 23



(A) Occupancy of *Gopherus agassizii* in the Mojave Desert of California. Sites of high suitability are color-coded in blue, low occupancy in red. B) 2060-2069 Habitat Suitability across California (based on a Regional Climate Model). Predicts warming and drying that converts Central Valley, Salinas Valley, and Santa Cruz sites to current-day desert climate in the Mojave-the tortoise will be extirpated from all Mohave sites (red-yellow).

TAKE HOME MESSAGE:

- The region harbors diverse reptile and amphibian taxa because many northern and southern species have overlapping ranges.
- For northern taxa, this poses a risk of extinction and several species have already registered local extinctions. Species may have robust climate refugia in the Santa Cruz Mountains and Santa Lucia Mountains that protect from the risk of extirpation owing to cooler temperatures and higher levels of precipitation.



Rivers, Streams and Riparian Areas

David Herbst

INTRODUCTION: SYNDROME OF EXTREMES

The Central Coast Region has more than 17,000 miles of surface waters (linear streams/rivers) and approximately 4000 square miles of groundwater basins (RWQCB 2012). The river systems of the central coast drain to western Pacific slopes and eastern interior slopes of the Santa Cruz and Santa Lucia mountains, and portions of the western Transverse ranges. In the southern and interior areas, climate is drier and even large rivers can have dry stretches.

Water diversions, flow regulation, and dams are widespread, and only a few major rivers have few or no dams (Big Sur, Arroyo Seco, and San Lorenzo). The Salinas River is the longest river in the Central Coast, running 175 miles (282 km). It flows north-northwest over 283 kilometers (109 miles) and drains the narrow and fertile Salinas Valley. Its major tributaries are Arroyo Seco, San Antonio and, Nacimiento. Grazing and natural lands exist in the surrounding foothills and mountainous areas, with agricultural and urban developments on the Salinas Valley floor.

The central coast streams are characteristic of Mediterranean climates (med-streams) and reflect strong seasonal precipitation patterns of winter/spring-wet high flows, and summer/fall-dry low flows, often with flash flows during storm episodes. Climate change is likely to increase the amplitude of this pattern with drought and flood extremes, and further drying of many streams.

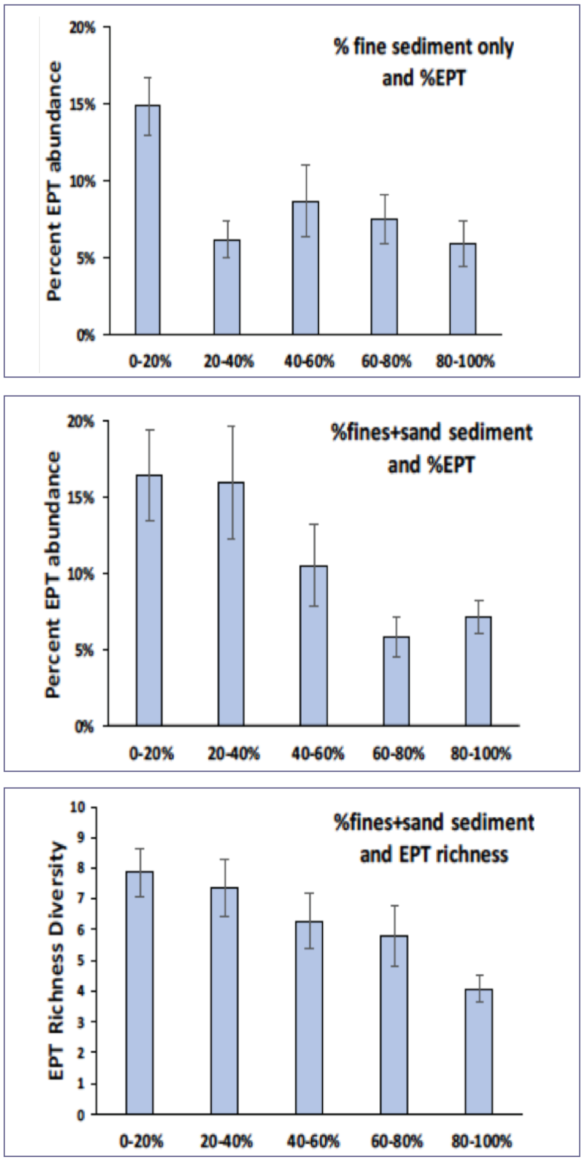
BIOLOGICAL RESPONSES

Some trends noted in the responses of med-stream biota to climate change include displacement to higher elevations and latitudes to match habitat requirements, homogenization of diversity among habitats, and prevalence of life history traits conferring resistance or resilience such as small size, short life cycles, and adaptations for desiccation (Felipe et al. 2013, Lawrence et al. 2010). Even though precipitation projections are uncertain, rising temperatures will intensify low stream flows that are likely to disrupt longitudinal and lateral channel connectivity and can become isolated stagnant pools with poor water quality.

Invertebrates of Central Coast streams have distinct summer-dry and winter-wet seasonal communities, related to their Mediterranean climate (Cooper et al. 1986, McElravy et al. 1989). Under climate change, extreme rainfall events are projected to increase, producing floods, erosion, scouring of channels, and sediment deposition as flows recede. Benthic (bottom dwelling) macroinvertebrates (mostly aquatic insects) inhabit stream bottom environments. They play key roles in food web function and diversity and can serve as indicators of changing habitat and water quality conditions. They also provide important food sources to fish and riparian birds. Extended drought periods may especially endanger the wet season species of these streams such as the sensitive EPT insect groups (e.g. Ephemeroptera or mayflies, Plecoptera or stoneflies, and Trichoptera or caddisflies) which are important in food webs and have been observed to decrease in numbers and diversity during severe drought. More tolerant groups like small midge flies (Chironomidae) may increase during drought (Lake 2011).

Studies of responses to the cover of deposited sediments have shown that above a range of >20-40 percent cover by fine and sand sediment deposits (>20 percent if fine sediment alone) on stream bottoms, there is a significant decline in the relative abundance of the sensitive EPT, and gradual reduction in their diversity (Herbst et al. 2016) (Figure 24). Along with urban and agricultural development, and with high sediment supply in the dominant sedimentary geology of the region (Pffeifer et al. 2017), deposition of life-choking sediment adds to already disrupted systems.

FIGURE 24



Sediments reduce proportion and diversity of sensitive insects. Responses of sensitive benthic insects such as mayflies, stoneflies & caddisflies (EPT) to cover by fine and sand sediment (< 2 mm) across 24 streams of the central coast region (excludes sediment-tolerant mayfly Tricorythodes). Figures are for fine sediment alone, and fine and sand sediment as they affect the percent of EPT, as well as the fine and sand sediment influence on the number of EPT species (means, with standard errors) (Herbst et al. 2011).

Under severe stress of low flow, floods, and erosion, some benthic invertebrate groups may suffer declines or extirpations while those tolerant of stress may benefit. Most taxonomic data from stream collections in the area, however, are available just at the genus-level for the aquatic larval stages of stream insects, so species-level distributions and conservation status are poorly known (Ball et al. 2013)

Fire in riparian zones of med-streams reduces canopy cover, increases water temperature, and produces increased sediment flux compared to unburned areas (Cooper et al. 2015). This alters the food web of burned streams, with increased density of algae and decreased terrestrial vegetation inputs, resulting in more invertebrate algae consumers and fewer detritovores.

Steelhead and Coho salmon are of prominent concern among the native fish of the central coast (Moyle et al. 2017). While steelhead range through this region, this is the southern limit for Coho, with a few recent observations (2015) in the area north of Santa Cruz (Scott Creek and Pescadero Creeks for example). Although the central and south-central coast have existing populations of steelhead, these are diminishing and National Marine Fisheries Service (NMFS) considers the species to have low to moderate recovery potential (Moyle et al. 2017). Poor juvenile survival in freshwaters is thought to be the primary impediment to recovery of these anadromous salmonids.

Reproductive timing is seasonal in steelhead, with spawning during high winter flows and summer migration of juveniles into streams, outlet lagoons, and estuaries. Climate change will exacerbate problems for the persistence and recovery of salmonids in this region due to reduced availability and accessibility of steelhead and coho habitat owing to decreasing stream flows, increased temperatures, and constricted habitat with altered food webs. Lower stream flows and higher summer water temperatures will stress salmon populations that have freshwater rearing in summer and depend on sustained flows (Grantham et al. 2012).

Lagoons forming in the lower areas of some streams where juvenile steelhead develop may become isolated and excessively saline as well as warm and stagnant. Winter flooding during storm runoff events may also reduce the early life stage survival rates for anadromous salmon. Altered estuary habitats at the lower end of many rivers and streams provide crucial habitat for the growth and survival of juvenile fish but have been highly modified by encroaching urbanization, agriculture, and the withdrawal of flows. Coho salmon conservation is at a critical level of concern with the populations in this southern area of their range. The Monterey Bay Salmon and Trout Project are pursuing intervention through a hatchery to recover Coho and steelhead stock. (https://mbstp.org/hatchery/). Removal of the San Clemente Dam from the Carmel River in 2015 provided the opening of possible new spawning habitat.

For both aquatic invertebrate and fish, survival under the changing hydroclimatic regime will depend on the availability of refuge habitat such as perennial headwaters, cooler groundwater input zones, and the breaching of lagoon sand bars in lower reaches (Robson et al. 2013). A practical measure to protect stream habitat, based on research results, is the action taken by the Central Coast Regional Water Quality Control Board to identify impacted riparian areas for erosion control. In addition, NMFS is spearheading multispecies recovery plans, working with landowners to recover stream and estuarine habitat quality for spawning and survival throughout the mixed-use landscapes of the California coast (NMFS 2016). This includes improving freshwater quantity and quality, floodplain connectivity, riparian habitat extent and in-stream cover features, availability of forage such as aquatic invertebrates, and unobstructed migratory passage ways.

Riparian Areas

Riparian vegetation corridors of streams are integral components of stream and river ecosystems. These zones link the water with the land, providing, among other benefits, a thermal refuge and shading of streams, inputs of organic matter, and protective filtering capacity from overland runoff. These streamside vegetation zones are also vulnerable to warming and drought. A review of multiple studies shows that >30 days of summer drought on average produces losses of plant biomass across many species, with lower seedling survival of cottonwood and willow but not exotic Tamarisk (Garssen et al. 2014). These impacts would narrow stream corridors and wetland zones, reducing the benefits conferred in intact riparian areas. Targeted restoration practices may enhance their adaptation to these impacts and provide "hotspot" opportunities for offsetting climate impacts (Capon et al. 2013).

TAKE HOME MESSAGE

- Aquatic life of streams and rivers are threatened by extreme swings from drought to floods and exacerbated by fire and erosion that buries habitat in sediments. This restricts survival conditions for already endangered migratory Steelhead and Coho salmon, and could further reduce the diversity and abundance of sensitive aquatic insects.

Central Coast Sandy Beaches

Jenny Dugan

Sandy beaches make up more than 50 percent of the open shorelines of the Central Coast, but the relative amount of sandy beach and beach characteristics vary greatly by county. They range in size from tiny pockets of sand in rocky coves to miles of uninterrupted sand. Although restricted to a narrow coastal strip, sandy beaches are highly valued by society for recreation, aesthetics, and cultural identity (Figure 25).

FIGURE 25

A wild sand dune-backed beach on Vandenberg AFB

Perched at the dynamic boundary of land and sea, sandy beach ecosystems are strongly influenced by marine and terrestrial processes, many of which will be profoundly affected by climate change (Vitousek et al. 2017ab). They are part of a larger system of surf zone, beach, and backshore. The sand in this larger system is constantly moving in response to winds, waves, currents, and tides. Sand supply dynamics to beaches is a key component that is strongly influenced by watershed scale processes and features including precipitation, fires, floods, and dams (Griggs et al. 2005).

Sandy beach ecosystems of the Central Coast support diverse, abundant, and unique intertidal biota and provide vital ecological functions (Dugan et al. 2003, 2015; Nielsen et al 2013, Defeo et al 2009, Schooler et al 2017). Ecosystem services and functions of beaches and dunes include the absorption of wave energy, the filtration of large volumes of seawater, nutrient recycling, rich endemic invertebrate communities that are important prey resources for shorebirds and fish, and the provision of critical habitat for wildlife, such as pinnipeds, declining and endangered species including shorebirds, and beach-nesting fish, like the California grunion (Dugan and Hubbard 2016).

Shorebirds exemplify the wildlife that rely on Central Coast beaches as wintering and migration habitat. Many species of shorebirds can spend the majority of each year (~8 months) on Central Coast beaches, leaving to migrate to breeding grounds in the spring and returning by late summer or early fall. The assemblage of wintering and migratory shorebirds using beaches can be remarkably abundant (> 100 birds km^{-1} per survey year round) and rich with more than 30 species observed at a single beach in Santa Barbara county (Hubbard and Dugan 2003). Shorebird abundance and diversity are significantly correlated with the abundance and diversity of intertidal invertebrate prey on Central Coast beaches (Dugan et al. 2003, 2015). The majority of the state's population of the federally listed Western Snowy Plover (Figure 26) nest on sandy beaches in the Central Coast (Page et al. 1995). Key nesting habitats for this species include beaches associated with major dune fields on the shores of Monterey Bay, Morro Bay, Oceano Dunes, Guadalupe Dunes, and Vandenburg Air Force Base.

Sandy beaches of the Central Coast support some of the most diverse intertidal invertebrate communities ever reported for these ecosystems with >45 species found in single surveys and >100 species recorded (Dugan et al. 2003, 2015, Schooler et al. 2017). Mobile crustaceans, insects, polychaete worms, and mollusks make up the majority of intertidal invertebrates on Central Coast beaches (Dugan et al. 2015, Nielsen et al. 2013). Endemic intertidal insects of beaches include a number of flightless beetles, such as the globose dune beetle (*Coelus globosus*), a state species of concern, and the pictured rove beetle (*Thinopinus pictus*) (Table 8). Wider beaches on the Central Coast often support sand-trapping pioneering vegetation, including unique plants and coastal strand communities (Table 8). These beaches are can be strongly linked geomorphically and ecologically to major coastal dune fields, such as the dunes associated with the Santa Ynez, Santa Maria, and Pajaro Rivers.

Sea level rise and extreme storms associated with global climate change, are expected to intensify pressures on beach ecosystems by increasing rates of shoreline erosion and degrading and fragmenting beach habitat (Schoeman et al. 2014, Vitousek et al. 2017ab). These impacts will be most severe on urbanized coasts where coastal land uses, armoring, and development constrain the evolution and retreat of the shoreline with rising sea resulting in "coastal squeeze" (Schlacher et al. 2007). The physical responses of beach ecosystems to sea level rise may be similar to that observed in episodic El Niño Southern Oscillation (ENSO) events (Revell et al. 2011, Barnard et al. 2017), although the time scale will differ greatly.

In response to climate forcing, many sandy beaches in the region are expected to become narrower, steeper, and coarser, and once continuous stretches of sandy beach will be interrupted by submerged coast or drowned beaches. The resulting habitat loss, fragmentation, and alteration carry profound ecological implications for the region's beach ecosystems. Although beaches are often assumed to be robust, disturbance-adapted ecosystems, findings of strong and lasting negative anthropogenic impacts suggest that beaches are sensitive to disturbance and can be slow to recover (Hubbard et al. 2014, Peterson et al. 2014).

Projected responses of beach ecosystems to sea level rise will be strongly affected by the potential for the shoreline to retreat. The nature of the landward boundary and the degree of human alterations such as coastal armoring and development are key factors in projecting the vulnerability and responses of beach ecosystems. Beaches with enough space to evolve and retreat landward (combined with a sufficient sand supply) will be better able to adjust to changing water levels and maintain biodiversity and ecosystem integrity with rising sea levels, often at the expense of adjacent coastal dune habitat (Schoeman et al. 2014). Where landward retreat is constrained by resistant sea cliffs or coastal armoring and infrastructure, beach ecosystems and their biota and functions will disappear as sea level rises.

For example, to the east of Point Conception, 78 percent of the beaches in southern Santa Barbara County are backed by coastal bluffs which greatly limits their scope for response to SLR. A case study by Myers et al. (2017) using the COSMoS model (Barnard et al. 2014) projected a significant loss of the critical upper beach habitat zone that will manifest with as little as 50 cm (1.64 feet) of SLR on bluff-backed beaches. Beaches with shoreline armoring that occupies upper beach zones and limits migration of the shoreline were projected to a more rapid loss of upper and mid beach zones with SLR. The upper beach zones of dune-backed beaches lost ground to but were projected to have greater resilience to SLR. The threat posed by habitat loss from SLR is projected to be greatest for the biota, wildlife, and ecological functions of the upper shore zones of beaches (Table 8) (Hubbard et al. 2014).

TABLE 8 - NATIVE SPECIES VULNERABLE TO DECLINE

SPECIES	COMMON NAME (FAMILY)
BIRDS:	
Charadrius nivosus nivosus	**Western snowy plover** (nesting)
Charadrius vociferous	Killdeer (nesting)
Sternula antillarum browni	**California Least Tern** (nesting)
Passerculus sandwichensis beldingi	**Belding's savannah sparrow** (foraging)
FISH:	
Leuresthes tenuis	California Grunion (Atheriniopsidae)
INVERTEBRATES:	
Tylos punctatus	Isopod (Tylidae)
Alloniscus perconvexus	Isopod (Alloniscidae)
Megalorchestia spp	Beachhoppers (Talitridae)
Dychirius marinus^	Beetle (Carabidae, flightless)
Cincindela spp.	Tiger beetle (Cincindelidae)
Thinopinus pictus^	Pictured rove beetle (Staphylindae)
Hadrotes crassus^	Rove beetle (Staphylindae)
Coelus globosus*^	**Globose dune beetle** (Tenebrionidae)
Endeodes spp.^	Soft-winged flower beetle (Melyridae)
PLANTS:	
Abronia maritima*	**Red Sand-Verbena** (Nyctaginaceae)
*Abronia umbellate**	Pink Sand-Verbena (Nyctaginaceae)
*Atriplex leucophylla**	Beach saltbush (Amaranthaceae)
*Ambrosia chamissonis**	Silver beach bur (Asteraceae)

Selected native species of the upper intertidal and coastal strand zones of Central Coast beaches that are vulnerable to declines in abundance or distribution with SLR (bold = special status species). (Coastal strand zone, flightless insects) (after Hubbard et al. 2014, Myers et al. 2017).

Extending from the landward boundary of the beach to the high tide line these zones are also where the majority of residential development, mechanized manipulations, and intense human recreational activities occur. At the same time, these upper shore zones are vital habitat for the diverse wildlife that require beaches for nesting or nurseries, such as snowy plovers and grunion (Figure 26).

FIGURE 26

Two representative vulnerable species that use upper beach zones for nesting in the Central Coast Region.
Left: Precocial Western Snowy Plover chick feeding on a beachhopper. Source: C. Bowdish.
Right: California Grunion spawning on a spring high tide night at the high tide line Source: D. Martin.

Upper shore zones support > 40 percent of the intertidal invertebrate species of beaches, including numerous endemic species that lack planktonic larval stages and consequently have limited dispersal and recolonization abilities (Dugan et al. 2003, 2008, Hubbard et al. 2014). Some of these vulnerable species play a major role in processing the inputs of macrophyte wrack that fuel a major component of beach food webs (Lastra et al. 2008) and cycle nutrients through beaches (Dugan et al. 2011). The reliance of beaches on subsidies from other marine ecosystems also means that climatic change effects on source ecosystems, such as kelp forests, can strongly affect beach consumers and food webs (Revell et al. 2011).

The effects of ocean warming and acidification will affect a wide variety of marine ecosystems (Poloczanska et al. 2013). For Central Coast beaches where many of the dominant invertebrate species inhabit a central portion of their geographical ranges, major range shifts with warming are not anticipated. However, temperature effects on the population demography of these dominant beach invertebrates could be important. Body size is expected to decline significantly with temperature for three major trophic groups of crustaceans (suspension-feeding hippid crabs, scavenging isopods, and wrack-consuming talitrid amphipods (Jaramillo et al. 2017)). This strong phenotypic response to ocean warming has important implications for survival and reproduction of intertidal populations as well as for the productivity of beach food webs and the provision of prey for wildlife and fish.

Conserving Central Coast beach ecosystems facing a rising and warming sea is a formidable challenge. A variety of approaches could be incorporated into conservation planning to enhance the resilience of soft sediment coastal ecosystems, including beaches and wetlands, to climate change and sea level rise. Promoting the use of ample setbacks for any new coastal development and identifying locations and opportunities where existing or derelict infrastructure can be removed as part of "managed retreat" to allow beaches to evolve and migrate landward could increase opportunities to maintain and conserve the diversity and ecosystem function of beach ecosystems as sea level rises. Examples of opportunistic managed retreat include Fort Ord's Stillwell Hall project on Monterey Bay and the Surfers' Point project near the Ventura River mouth. Restoring the biodiversity, dunes, and ecosystem function of intensively managed beaches that are currently degraded yet relatively wide could also provide opportunities to conserve vulnerable beach ecosystems with SLR. Allowing more of the sand from streams and watersheds to enter littoral cells and support coastal sediment budgets could provide additional scope for conserving beach ecosystems.

TAKE HOME MESSAGE:

- Many beaches will narrow considerably and as many as two-thirds, along with their ecosystems, will be completely lost over the next century
- Beach ecosystems responses to SLR will be strongly affected by the potential for shoreline retreat. Dune-backed beaches will be most resilient while those backed by bluffs and armoring structures will disappear.
- SLR impacts are projected to be greatest for biota and functions of the upper shore zones of all beaches.

Tidal Estuaries

Daniel Brumbaugh

Tidal estuaries are generally defined as semi-enclosed aquatic ecosystems – including the bordering wetland habitats – where freshwater meets the ocean. The exact character of these ecosystems can vary substantially, however, depending on the degree of enclosure and the dynamics of the marine and freshwater inputs. Coarsely classified, estuaries in the Central Coast region fall within embayment/bay, riverine, and lagoonal estuary types (Heady et al. 2014).

Because most of the Central Coast has narrow coastal plains abutted by hills, its estuaries (as well as their source watersheds) are mostly small, with 95 percent smaller than 100 acres (40 ha) (Heady et al. 2014). Many of these are bar-built lagoonal estuaries, found where seasonal creeks flow to pocket beaches, which may only be seasonally or intermittently open to the ocean when larger winter freshwater flows and oceanic swells overtop or erode restrictive sand bars (Heady et al. 2015). In contrast, the largest estuaries within the region are embayments – recesses in a coastline that form a bay (e.g. Elkhorn Slough (3,435 acres) (Figure 27) and Morro Bay (2,536 acres).

FIGURE 27

Aerial view of Elkhorn Slough. Source: Marli Miller, U. Oregon

Estuaries are often highly productive ecosystems due to combinations of external inputs from watersheds and marine communities, and the abilities of phytoplankton, benthic algae, and vascular plants to utilize and turnover nutrients made available by robust microbial activity (Cloern et al. 2016). This productivity, combined with shelter from many of the physical and biological disturbances of the open coast, allows estuaries to serve as important foraging and nursery areas for many wildlife species, including ones that support fisheries (Allen et al. 2006, Hughes et al. 2014).

Along the US West Coast, only about 15 percent of historical tidal estuary area remains (http://www.pacificfishhabitat.org/data/; L. Brophy, pers. comm.), and much of this has been heavily altered by a history of fragmentation and degradation through diking, tide gates, previous agricultural use, and introduction of non-native species. Estuaries are also impacted by surrounding land uses within watersheds, including depletion of surface and ground water sources, agricultural runoff of pesticides and fertilizers, urban runoff of other pollutants, and changes to sediment dynamics (Phillips et al. 2002).

Climate change – particularly through impacts such as accelerated sea level rise (SLR), warming of water and air, ocean acidification, and changes in runoff – affects estuarine ecosystems in multiple, interactive ways (Cloern et al. 2011). For example, current understanding of sediment dynamics and SLR modeling suggests that some Central Coast marshes lack sufficient sediment inputs to track SLR, and will drown, converting marshes to shallow mudflats. This will lead to a loss of the ecosystem services that marshes provide, including carbon sequestration.

Eutrophication from fertilizer runoff also promotes ephemeral algal growth on mudflats, which can smother other plant growth. In combination with warm water temperatures, this can ultimately lead to greater community respiration levels and repeated periods of hypoxia within portions of estuaries. In turn, hypoxia reduces suitable fish habitat, local fish diversity, and the abundance of fisheries species (Hughes et al. 2015). While estuarine species are generally adapted to daily and seasonal fluctuations in pH (Baumann and Smith 2018), projected trends of increasing acidification are also likely to exceed the tolerances of many species. Small organisms with calcium carbonate skeletons or shells (including many larval and juvenile invertebrates and other plankton) may be most affected. Therefore, in addition to broader ecosystem impacts, this raises concerns for oyster aquaculture in Morro Bay.

TAKE HOME MESSAGE:

- Accelerated SLR, warming of water and air, ocean acidification, and changes in runoff will have multiple effects on estuarine ecosystems. Some Central Coast marshes may drown or become shallow mudflats leading to a loss of the ecosystem services that marshes provide, including carbon sequestration

Effective management of tidal estuaries, therefore, increasingly requires both mitigation of local stressors like runoff and artificially restricted water circulation and sediment supply, as well as strategic adaptation through active habitat restoration and retreat in response to global stressors such as SLR.

Central Coastal Communities: Impacts and Adaptations

Changes in temperature, precipitation, extreme events, and sea level rise under climate change can adversely affect water supplies, energy systems, transportation, public health, and agricticulture. Vulnerable populations are disproportionately affected. This section first exacmines climate change impacts and adaptations for these sectors. Then it discusses community adaptations that are region-wide, and specific adaptations for municipalities and natural lands.

Freshwater Resources

Ruth Langridge

INTRODUCTION

The Central Coast faces unique water challenges under climate change. The region receives its water from three main sources: 1) local surface water, 2) limited imported surface water from the Sierra Nevada Mountains via the SWP, and 3) groundwater basins that are already stressed. Recycled water and desalinated water currently provide lesser amounts, however, recycled water projects have increased in the region and several areas are considering new desalination projects. Many service sectors as well as communities rely primarily on regional reservoirs and groundwater.

Local surface water is provided by runoff that feeds Central Coast rivers and streams and is stored in many local reservoirs. Examples are the Salinas Dam, built in 1942, the Nacimiento Dam, built in 1956, and the San Antonio Dam built in 1965. Larger reservoirs include Catchuma and Twitchell, owned by the federal government and operated by local water purveyors. Runoff from the Santa Lucia Range, west of the Salinas Valley, provides most of the annual water supply to the Salinas River and major tributaries (Arroyo Seco, San Antonio, and Nacimiento). Streams fed by runoff from the eastern mountains, are generally dry from summer to fall due to that area's drier climate. The southern-most mountains of the region receive similar amounts of rainfall as the mountains to the north. Major watersheds include Pescadero, San Lorenzo, Pajaro, Carmel, Little Sur, Big Sur, Sisquoc, Cuyama, and lower Santa Ynez.

Groundwater is a second critical source of water and the region includes 53 groundwater basins encompassing 3559 square miles. Agriculture and many local cities rely extensively on groundwater, with some areas and communities almost 100 percent reliant on groundwater (e.g. Soquel Creek, Pajaro Valley, and Salinas Valley). But over 40 percent of the groundwater basins in the region are already ranked as either "high" or "medium" priority by the 2014 California Groundwater Elevation Monitoring (CASGEM) prioritization, indicating they are seriously threatened by future increases in groundwater demand (Martin 2014).

Imported water from the State Water Project is a third major water source for many areas for both consumptive use, including drinking water and irrigation, as well as for groundwater recharge. Recycled water and desalinated water currently provide smaller amounts for consumptive use.

CLIMATE IMPACTS ON WATER SUPPLIES

Water supply shortages are already a serious problem for many areas of the Central Coast. Inter-annual water availability is variable and localized and the Central Coast region, like the entire state, experiences periodic droughts (see Extreme Drought section). Absent adaptations, extreme droughts and rising temperatures will exacerbate water supply deficits. Moreover, fewer but more severe rainfall events are projected (Swain et al. 2018) which will result in intense run-off that may overwhelm sewer and treatment facilities and potentially negatively affect stream and coastal water quality. Currently, there is insufficient infrastructure to harness that surplus of local water.

Climate change will affect imported water from the State Water Project (SWP). Higher temperatures will result in reduced Sierra mountain snowmelt, with runoff timing changes and more frequent occurrence of a warm snow drought, defined as "above or near average accumulated precipitation coinciding with below average snow water equivalent at a point in time" (Hatchett and McEvoy 2017, Belmecheri, Babst, Wahl, Stahle, and Trouet, 2016). The DWR predicts that "SWP deliveries will decrease by 5.6 percent due to climate change and environmental concerns in the delta" if major improvements to delta infrastructure are not pursued (Kerckhoff et al. 2013). Additionally, SWP water will likely cost more in the future (Connell-Buck, Medellín-Azuara, Lund, and Madani, 2011, Harou et al. 2010).

Groundwater, a main water supply source, will also be impacted by climate change. Research on the dynamic relationship between groundwater, drought, and climate change is relatively limited compared to surface water studies (Brouyère et al. 2004, Hsu et al. 2007, Bates et al. 2008, Clifton et. al. 2010), and overall the effects of climate change on groundwater quantity and quality remain uncertain (Cisneros et al. 2014). Nevertheless, reduced imported water from the SWP and declining spring and summer streamflows will limit surface water supplies, shifting reliance to already overdrafted groundwater resources (Hayhoe et al. 2004, Langridge et al. 2016). More extreme droughts and higher temperatures will also alter the natural recharge of groundwater and potentially exacerbate groundwater overdraft. Reduced groundwater storage limits the use of groundwater as a backup supply during drought.

One of the most persistent water quality problems in the region, the intrusion of salt water into groundwater aquifers and wells, could potentially increase under climate change depending on the implementation of adaptation projects. In the Pajaro Valley, a productive agricultural area where irrigated agriculture is supplied by groundwater, source aquifers have been subject to overdraft and related seawater intrusion since the 1940's (Hanson 2003), and while the rate of intrusion has been reduced it has not been halted. Both the Pajaro Valley Water Management Agency and the Monterey Peninsula Water Management District have taken steps to reduce saltwater intrusion, including coastal distribution systems that provide recycled water to coastal growers to incentivize in-lieu recharge of groundwater. In the Salinas Valley, seawater intrusion due to groundwater pumping from local groundwater aquifers has already advanced since it was measured in 1944 (Salinas River Groundwater Basin Report 2015), migrating over 8 miles into the Salinas Valley aquifer system (Figure 28).

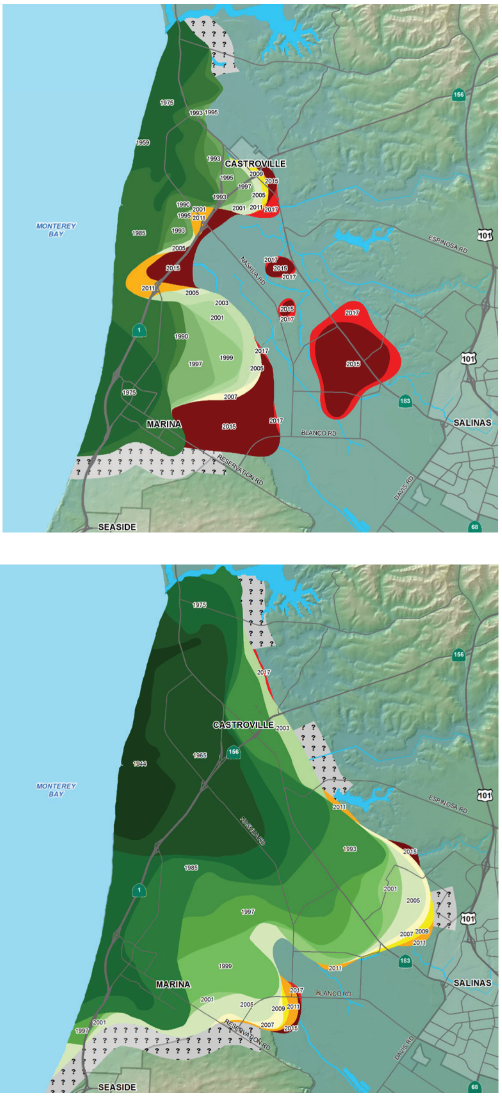
Pesticide and nutrient loading of pollutants including nitrates into the water supply is another issue. As noted, water for irrigation is extensive in the major Central Coast agricultural production areas, and this has led to nitrate pollution of drinking water supplies - a critical problem throughout the region. Fertilizer from irrigated agriculture is the largest primary source of nitrate pollution in drinking water wells (Carle et al. 2012). It is estimated that tens of millions of pounds of nitrate leach into groundwater in the Salinas Valley alone each year. Hundreds of drinking water wells serving thousands of people throughout the region have nitrate levels exceeding the drinking water standard (RWQCB 2012, Harter et al. 2012). The nutrients in agricultural runoff also have significant impacts to downstream estuaries, and eutrophication decreases salt marsh resilience through proliferation of algal mats (Wasson et al. 2017).

Studies of soil processes suggest climate change is likely to lead to an increased nitrate leaching rate from the soil under future climate scenarios. While not fully understood, predictions are that under future climate scenarios, changes in the hydrological cycle will affect groundwater recharge, groundwater levels and flow processes. Pathways by which nitrate enters groundwater will therefore be modified (Stuart et al. 2011).

Agricultural use of pesticides in the region, with associated toxicity, is also high, and agricultural discharges of pesticides have severely impacted aquatic life in Central Coast streams (Anderson et al. 2003, 2006a, 2006b). Groundwater contamination is a major issue for small, disadvantaged rural communities. Over two-dozen small systems (population less than 3,300) have contaminated wells and health violations (Hanak et al. 2014). Efforts to reduce pollution are ongoing (RWQCB 2012).

Finally, demographic factors including changes in population and agricultural practices (potentially from annual crops to orchards and vineyards) also present challenges in planning for future water supply and demand in the region under climate change. Conversions of grasslands, shrublands, and agriculture to developed land were two common land-cover changes in the Central California Chaparral and Oak Woodlands Ecoregion. Projecting land-use change data for the state as a whole over the 50 years from 2012 to 2062 revealed the following potential changes that are also relevant to the Central Coast: large amount of grassland habitat loss over 50 years that will exacerbate challenges in preserving and recharging aquifers; an overall increase in applied water demand due to urbanization and expansion of berries and vineyards; and shifts from annual to perennial crops, which removes flexibility in irrigation demand during drought. (Wilson et al. 2016)

FIGURE 28



Summarizes the rates of seawater intrusion from 1944 to 2013 for the 180-foot (top) and 400-foot (bottom) aquifer in the Salinas Valley, as measured from the historical extents. Source: Monterey County Water Resources Agency 2018.

dark green=1944, purple =2015, red = 2017

Box 3: Summary of Potential Climate Change Impacts to Central Coast Water Resources (changes in temperature, evapotranspiration, extreme droughts)

- Agricultural water use is likely to increase
- Domestic landscaping water demand will be higher
- Groundwater extraction may increase
- Rate of saltwater intrusion may increase
- Lower seasonal surface flows will lead to higher pollutant concentrations and affect nitrate inputs, soil processes and agricultural productivity
- Changes in rainfall patterns will affect the release of surface water from reservoirs
- Imported water from the SWP will be less reliable and more expensive

ADAPTATIONS

When polled by the Central Coast Climate Collaborative, many Central Coast cities and counties pointed to drought and declining water supplies as a top natural hazard concern for the region (Central Coast Climate Collaborative 2018). To adapt to the impacts of climate change on water resources, water agencies are utilizing a variety of strategies that focus on increasing overall water supplies as well as increasing groundwater storage.

Recycled water use has increased in the region. Most growers in the northern Salinas Valley have been using recycled water since 1998. Two studies concluded that the use of recycled water caused an increase in soil salinity in the area; however, the Sodium Adsorption Ratio (SAR) values are not deleterious and Na has shown little accumulation in the rooting zone. An ongoing study, started in 2000, is evaluating the possible long-term effects from the use of varying levels of recycled water (tertiary-treated wastewater) in Monterey County on soil salinity and cool-season vegetable and strawberry production (Platts and Grismer 2014).

Desalination can also be a reliable source of water, especially during a drought, and several new desalination facilities have been proposed (e.g. Monterey Peninsula Water Supply Project, DeepWater Desal, and The People's Moss Landing Water Desalination Project) (CSUMB 2018, Pacific Institute 2016). In March 2018, the City of Santa Barbara was awarded a $10 million grant by the California Department of Water Resources (DWR) to offset the $72 million cost of reactivating its Charles Meyer desalination plant. The plant was initially constructed in the 1980s and then placed into standby mode until 2015 when the Santa Barbara City Council voted to reactivate it (City of Santa Barbara 2018). A major issue with desalination is that the energy requirements are significantly more than for other water supply sources, a key factor that will impact the extent and success of desalination (Cooley and Herberger 2013).

The 2014 Sustainable Groundwater Management Act (SGMA) will also potentially result in more sustainable management of groundwater, a critical resource for many Central Coast basins and especially important during drought. Management is now required to reduce or halt groundwater depletion, saltwater intrusion, and other unacceptable impacts (SGMA - AB 1739, SB 1168, and SB 1319). While SGMA does not directly provide incentives to manage groundwater with pro-active long-term strategies that account for climate change and drought, it is implicit in its requirements for sustainability, and water districts are utilizing a variety of approaches to adapt groundwater management to climate change. For example, strategies are being developed by several water agencies that focus on establishing groundwater drought buffers and these may be particularly effective in reducing drought impacts under climate change. The Monterey Peninsula Water Management District negotiated with growers to provide water for groundwater recharge in exchange for a drought reserve supply. The Goleta Water District established a groundwater reserve to be used exclusively during drought (Langridge et al. 2018).

The intensity of climate extremes is projected to increase with climate change (Tebaldi et al. 2006) and they can present additional opportunities for storing water for use during drought. Vázquez-Suñé et al. (2007) found that recharge from flooding helps explain major head recoveries. O'Geen et al. (2015) used data on soils, topography, and crop type to develop a spatially explicit index of the suitability for groundwater recharge of land in all agricultural regions in California including: deep percolation; root zone residence time; topography; chemical limitations; and soil surface condition. Kochis and Dahlke (2015) analyzed the magnitude, frequency, duration, and timing of high-magnitude streamflow for 93 stream gauges covering the Sacramento, San Joaquin, and Tulare basins in California. Their results show that, in an average year, significant high-magnitude flow is exported from the entire Central Valley to the Sacramento-San Joaquin Delta, often at times when environmental flow requirements of the Delta and major rivers are exceeded, suggesting that significant unmanaged surface water is physically available for recharge and storage.

TAKE HOME MESSAGE

- Water supply shortages, already common during drought, will be exacerbated.
- Higher temperatures and more extreme droughts will likely result in increases in water demand for agriculture and landscaping.
- Reduced surface water will likely lead to increased groundwater extractions, potentially leading to increases in saltwater intrusion and higher pollutant concentrations.
- Climate change will affect reservoir storage and SWP water reliability.

Agriculture

INTRODUCTION AND CLIMATE IMPACTS

The combination of flat land, well-textured alluvial soils, groundwater irrigation technology, long rain-free periods, and the air-conditioning effect of coastal fog associated with offshore upwelling facilitates agricultural development in the Central Coast region. Two crops per year can often be grown (staggered to optimize marketability) and the production value of agriculture has increased since 2012 in every county. A large variety of crops are grown with truck nurseries, berries, and vineyards dominating and strawberries the leading berry crop (Tourte 2018).

The Central Coast Region has approximately 435,000 acres of irrigated land and approximately 3000 agricultural operations. Most agriculture involves the use of fertilizers, soil amendments, herbicides, and pesticides, and water quality issues are a concern. There is substantial empirical data demonstrating that water quality conditions in agricultural areas of the region continue to be severely impaired or polluted by waste discharges from irrigated agricultural operations. These discharges impair drinking water and aquatic habitat on or near irrigated agricultural operations. The most serious water quality degradation is caused by fertilizer and pesticide use, which results in runoff of chemicals from agricultural fields into the region's more than 17,000 miles of surface waters (linear streams/rivers) as well as the percolation into groundwater (RWQCB 2012).

Agricultural production is highly sensitive to climate change including the amounts, forms, and distribution of precipitation, changes in temperatures, and increased frequency and intensity of climate extremes. Irrigated agriculture produces most of the harvested crops and a decrease in water availability could potentially reduce crop areas and yields (Tanaka et al. 2015). Additionally, lower stream flow and groundwater levels as a consequence of more extreme droughts will harm crops by increasing the risk of wildfires when soil surfaces dry out. While permanent crops are among the most profitable, they require several years to reach maturity and profitable production, they cannot be fallowed and are therefore more vulnerable during droughts, and they are sensitive to even relatively small temperature changes during critical development stages and/or close to harvest (Pathak et al. 2018). These impacts can affect food security issues.

Viticulture is present in several areas and continues to grow today. In Monterey County, there were 21,000 acres of vineyard in 1991. Ten years later, the amount of acreage increased to 38,000, producing a crop worth $209 million (Agricultural Commission 2001). Vineyards installed on steep land can become areas of erosion during heavy rain if techniques (including contouring rows and cover crops) are not utilized. Vineyards can also be significant sources of sediment during start-up years due to the substantial disturbance of land required for planting preparation.

The fresh market berry industry in Santa Cruz and Monterey counties has seen dramatic growth in strawberry, raspberry, and blackberry production over the last 50 years, most notably since the 1980s (Figure 23) (Tourte et al. 2016). The Pajaro Valley was initially known for its apple crop, but strawberries now dominate along the coast. The strawberry industry faces some serious challenges, including invasive pests and the phase out of the soil fumigant methyl bromide. Moreover, land where strawberries are grown is especially vulnerable to erosion as many fields are covered in plastic, creating an impermeable surface for runoff.

The Salinas Valley is identified as one of the most vulnerable agricultural regions under climate change (Jackson 2012). The amounts, forms, and distribution of precipitation, as well as the increased frequency and intensity of climate extremes, will affect water availability as well as pests, crop yields, and the length of the growing season. Climate change could also impact agriculture in the region by increasing the demand for irrigation to meet higher evaporative processes. Oehninger et al. (2016) found that changes in climate variables will influence crop selection decisions, crop acreage allocation decisions, technology adoption, and the demand for water by farmers, and that such changes in behavior can affect the diversity of crops planted, potentially impacting agricultural biodiversity.

Many permanent crops are sensitive to small temperature changes during development stages and/or close to harvest. Threshold temperature impacts can affect dairy production and wine grape quality. For example, the yields for wine

grapes and strawberries may be reduced due to warm winters. Plant diseases, insects, and invasive weeds are also affected by temperature related climate factors (Pathak et al. 2018). Various model scenarios also suggest that forage production for cattle grazing might decline because of decreases in annual precipitation

Climate change also has the potential to impact water availability. It may cause farmers to change the crops they plant, affecting water demand and the amount of water they apply. Adaptation options to shift varieties or locations of production would require significant time and capital investment.

ADAPTATIONS

Agricultural Vulnerability Indices (AVI) are used to reflect climate risks. They examine biophysical and social indicators over time and space. The AVI assigns each variable to one of four sub-indices: climate vulnerability, crop vulnerability, land use vulnerability, and socioeconomic vulnerability based on an a priori judgment and spatial resolution. The AVI for California integrates biophysical and social indicators relevant to state and local efforts to adapt to changes in climate, land use, and economic forces, and is meant to be a starting point for "place-based" adaptation planning for agriculture. To date, there is no single data point to measure crop vulnerability across the landscape (Pathak et al. 2018). Merging coupled crop and economic models may provide a better picture of specialty crop vulnerability (Kerr et al. 2017). The Social Vulnerability Index (SVI) is used to explore vulnerability to environmental hazards. As noted, the Salinas Valley is identified as one of the most vulnerable agricultural regions (CEC 2018).

Adaptation proposals (Pathak et al. 2018) include:

- Improving water use efficiency with improved irrigation management and by adapting crop rotations and associated practices (tillage systems, soil cover management, etc.) to improve soil retention capacity improve water use efficiency in crops.
- Switching to low-chill crop varieties and altering planting and harvesting schedules.
- Prioritizing crop breeding strategies to select for traits with low-chill requirement temperate fruit and nut crops.
- Switching to low-chill varieties.
- Altering planting and harvesting schedules.
- Prioritizing crop breeding strategies to select for traits with low-chill requirement temperate fruit and nut crops.
- Adapting ad hoc crop rotations and associated and agricultural practices (tillage systems, soil cover management, etc.) to improve soil retention capacity.
- Shifting and diversifying crop mixes.

TAKE HOME MESSAGE

- Agricultural production is highly sensitive to climate change including amounts, forms, and distribution of precipitation, changes in temperatures and increased frequency and intensity of climate extremes. The Salinas Valley is identified as one of the most vulnerable agricultural regions under climate change.
- Changes in climate influence crop selection, crop acreage, technology adoption, and the demand for water. Such changes can affect the diversity of crops planted, potentially impacting agricultural biodiversity

- Working with farmers to minimize climate risks including shifting to more drought tolerant plants and using organic mulch to conserve water.
- Increasing water storage and using micro-irrigation systems.
- Shifting from traditional salt sensitive crops like strawberries to salt tolerant crops along the coast.
- Increasing research on crop responses to water deficits.

Public Health

Dharshani Pearson, Charlotte Smith, Rupa Basu

Climate change is projected to harm human health through increases in extreme temperature and extreme weather events, and decreases in air quality, vector-borne diseases, and harmful algal blooms.

EXTREME HEAT EVENTS

Increased temperatures that manifest as heat waves directly harm human health through heat-related illnesses and the exacerbation of pre-existing conditions in vulnerable populations. Heat waves are defined as five days over 79 degrees F to 85 degrees F along the coast, and 99 degrees F to 101 degrees F inland. Coastal areas should expect one more heat wave per year by 2050 and four to eight more per year by 2100. Further inland, three to four more heat waves are expected by 2050 and eight to ten more per year by 2100 (Public Interest Energy Research 2011).

Some populations inhabiting the Central Coast are especially vulnerable to the effects of more frequents extreme heat events. San Benito, Monterey, Santa Cruz, Santa Barbara, and San Luis Obispo counties have large farming and viticulture production, and heat waves and prolonged heat days in the area would increase the exposure of thousands of outdoor workers to heat-related illnesses, including vulnerable populations such as agricultural field workers (Cooley 2012) (Figure 29).

FIGURE 29

Salinas Valley strawberry pickers. Source: California Magazine.

In urban areas, the heat island effect, attributed to an increase in building heat load due to heat-absorbing structures and lack of green space, is exacerbated by more extreme heat events (Maizlish et al. 2017). In these and other areas, heat intensifies the number of photochemical reactions that produce smog, more fine particulates (PM2.5) and ground-level ozone pollution (Maizlish et al. 2017). Ground-level ozone is a respiratory irritant that can contribute to and exacerbate respiratory disease, and result in more asthma attacks, more heart attacks, decreases in lung function and increased hospital admissions and deaths (Rudolph et al. 2015).

In the 2006 California heat wave, emergency room (ER) visits in some Central Coast counties were elevated for diabetes, cardiovascular, and respiratory events [Knowlton et al. 2009}. The Central Coast region (a typically cooler climate zone) contributed far more to the overall excess ER visits (28 percent) and to excess hospitalizations (47 percent) than would be expected based on overall state population (18 percent) (Knowlton et al. 2009). Investigators attributed the increase to a lack of acclimatization among these residents who generally experience milder local temperatures (Knowlton et al. 2009). In examining the effects of temperature on hospitalizations in California from 1999-2009 during heat waves, Sherbakov et al. (2017) found a significantly higher risk for cardiovascular hospitalizations during heat waves for diabetics in coastal regions, including some Central Coast counties, compared to non-coastal regions. Other studies have used mapping tools to identify California regions are most at risk for heat vulnerability. Reid et al. (2009) mapped vulnerable geographic areas and identified specific areas of the Central Coast as being especially vulnerable.

Although air conditioning (AC) can alleviate some of the discomfort felt in extreme heat events and lower related morbidity, many coastal areas lack AC devices in their homes due to generally lower regional temperatures (California Energy Commission, Ostro et al. 2010). Unlike urban areas that have cooling centers – such as Los Angeles County, where 80 percent of households have access to a public cooling resource within walking distance (Fraser et al. 2017) – there are fewer close cooling places available to residents who lack AC at home. Moreover, indoor AC provides no protection for outdoor workers. In 2010, San Luis Obispo County had approximately 8,888 outdoor workers whose occupation increased their risk of heat illness (Maizlish et al. 2017). Adequate shade and misting stations could provide extra protection for such workers.

Extreme heat events in drought-ridden, low-humidity conditions in areas with significant vegetation also put vulnerable areas at high risk for wildfires, as seen in the 2013 Rim fire (Maizlish et al. 2017, a-e). All five counties in the Central Coast have areas designated as being high or very high in the Fire Hazard Severity Zone map (Maizlish et al. 2017), with heat wave events expected to rise in number and duration over the 21st century. Populations at high risk include: 12 percent of San Benito County, 14 percent of Monterey County, 22.9 percent San Luis Obispo County, 13 percent Santa Barbara County, and 24 percent Santa Cruz County (California Building Resilience Against Climate Effects (Maizlish et al. 2017, a-e). A wildfire during an extreme heat event would expose populations to smoke-associated particulate matter, inducing respiratory effects [Maizlish et al. 2017). Outdoor agricultural workers are again more exposed to the health effects of wildfire-induced particulate matter. Moreover, counties in the Central Coast include significant rural areas where older, more-isolated residents, already at risk, are more vulnerable to the effects of wildfire (Maizlish et al. 2017).

The National Weather Service provides heat wave warnings, but this strategy may offer less protection for Central Coast residents where outdoor temperatures are lower than in other regions. Lacking acclimatization to higher temperatures, residents could develop heat illness at lower temperatures. Central Coast areas could utilize the California Heat Assessment Tool (CHAT), a recently-developed statewide emergency tool that issues heat alerts specific to different areas of the state, taking into account temperature vulnerabilities among various populations (Steinberg et al. 2018).

VECTOR-BORNE AND INFECTIOUS DISEASE TRANSMISSION IN CALIFORNIA CENTRAL COAST

Rising temperatures and more extreme drought events are increasingly associated with an uptick in vector-borne and infectious disease transmission (Climate Change and Health 2016). Climate changes affect the life cycles of native tick species that can harbor bacteria or viruses causing Lyme disease and other illnesses, often extending their habitat range (Climate Change and Health 2016). Additionally, lack of soil moisture due to drought and evaporation from high temperatures increase dust particle concentration, which sometimes house harmful fungal spores and viruses, including *coccidioidomycosis* (valley fever) (Climate Change and Health 2016).

Cases of vector-borne disease, including Lyme disease, are expected to rise with climate change (Estrada-Pena, A., N. Ayllon, and J. de la Fuente 2012). However, in the Central Coast spread of the disease has been contained likely due to the area's drier climate and differing vegetation (MacDonald, A.J. et al. 2017). *Ixodes pacificus*, the tick species most responsible for hosting *Borrelia burgdorferi*, which causes Lyme disease, is present in the Central Coast, albeit in thinner population sizes (MacDonald, A.J. et al. 2017). However, *B. burgdorferi* has also been found in other tick species in the Central Coast, and their impact on Lyme disease transmittal in human populations warrants further investigation as little is known in this area (MacDonald, A.J. et al. 2017).

A newly-identified vector-borne disease, Pacific Coast tick fever (PCTP), is spread by *Dermacentor occidentalis*, which harbors *Rickettsia philipii*, the causative agent of the disease (Padgett, K.A., et al. 2016). Although still an emerging illness, a few of the human cases originated in the Central Coast. *R. Philipii* bacteria have also been identified in ticks found in the Coast (Padgett, K.A., et al. 2016). With PCTP exhibiting a summer trend so far, climate change and increasing temperatures have the potential to extend transmittal season in the Central Coast. West Nile Virus, a mosquito-borne illness that affects both humans and birds, has also made a presence in the Central Coast, though to a much smaller extent than other parts of California. At the end of 2017, Monterey, San Luis Obispo, and Santa Barbara Counties reported a handful of cases of West Nile found in sentinel chicken, bird or mosquito samples, but none reported any human cases (California Department of Public Health, UC Davis Arbovirus Research and Training 2018).

Despite relatively low cases of West Nile Virus and Lyme disease, the California Department of Public Health (CDPH) has also identified the Central Coast as a high-risk area for valley fever (California Department of Public Health 2017). The illness, transmitted by the *Coccidioides immitis* fungus, is found in disturbed, dry soil particles that are breathed in. Its symptoms include chest pain, exhaustion, fever, coughing, joint and muscle pain, and difficulty breathing, among other symptoms, and can persist for weeks or even months. Pregnant women, the elderly, African, and Filipino Americans are more vulnerable to the severe cases of the disease (Brown et al. 2013). In particular, the 2006 Santa Barbara fires, driven to a great extent by high winds, may have exposed some firefighters to the illness while they engaged in soil disruption and removing vegetation to prevent wildfire spread, and worked to stymie the flames in Cuyuma Valley, an area known for valley fever outbreaks (Bubnash 2017). Both Santa Barbara and San Luis Obispo Counties, where the valley fever fungus, *C. immitis*, is endemic, have reported large numbers of cases in 2017 (Bubnash 2017, Wilson 2016), with the CDPH reporting over 500 cases for these two counties in addition to Monterey County at the end of 2017 (CDPH 2017).

HARMFUL ALGAL BLOOMS

Harmful algal blooms (HABs), an already reoccurring and escalating issue throughout the state, will increase under climate change (A. Anderson-Abbs et al. 2016). Eating seafood contaminated by toxins from the algae Alexandrium can lead to paralytic shellfish poisoning. Pseudo-nitzschia produces the toxin domoic acid that can cause vomiting, diarrhea, confusion, seizures, permanent short-term memory loss, or death when consumed at high levels (National Institute of Environmental Health Services 2018). Cyanobacteria, also known as blue-green algae, inhabit a wide variety of aquatic environments and have the potential to produce cyanotoxins such as microcystins that adversely impact aquatic life, drinking water, and recreation activities. Microcystin-LR is a known hepatotoxin (liver toxin) (Lehman et al. 2017).

Algal toxins have made it unsafe to eat shellfish during periodic algal blooms. The California Department of Public Health routinely issues warning not to eat mussels, clams, and crabs along the California Coast due to this problem (Harmful algal Blooms 2018). Exposure can also result from swimming or breathing air in environments near HABs. The loss of revenue to the seafood industry and commercial fishermen is significant. The Woods Hole Oceanographic Institute (WHOI) estimated public health costs related to people eating tainted seafood to be between $18 to $25 million per year in 2000 dollars (Estimated Annual Economic Impacts from Harmful Algal Blooms in the United States 2018).

Harmful algal blooms are stimulated by nitrogen and phosphorus, and nutrient deposition is associated with point and non-point pollution sources. Waste water plants and consolidated animal feeding operations are point sources, and non-point sources are runoff from animal feeding operations (e.g., ranches) and farms or fields which utilize fertilizers. Non-point source inputs would be particularly concerning under a climate change scenario involving more frequent and severe precipitation events. State Pollutant Discharge Elimination System (SPDES) permits help monitor and control point sources, but non-point source inputs rely on voluntary actions such as appropriate application of fertilizers.

TAKE HOME MESSAGE

- Extreme heat events could increase heat-related illnesses for agricultural workers; spark wildfires in arid areas with high vegetation releasing harmful particulate matter affecting residents' respiratory health; and enhance the urban heat island effect by increasing ground-level ozone.
- Infectious/Vector-borne diseases may worsen, including an increase in Valley Fever and the emergence of Pacific Coast tick fever.
- An increase in harmful algal blooms will have detrimental effects on animals and people exposed to toxins released from the algae. Mitigation requires control of nutrients from agricultural runoff.

ADAPTATIONS

San Luis Obispo County Public Health Department (SLOCPHD) initiated the first climate change and health communications campaign in California. Launched in 2014, the campaign was co-developed with the California Department of Public Health (CDPH) and is supported by a wide array of community partners (Karle 2014).

Energy

Yihsu Chen, Na Chen

The energy sector is defined as including all the fuels, energy carriers (e.g., electricity), and infrastructure that provide energy services (Bruckner et al. 2014), which in California accounts for more than 80 percent of the state's annual greenhouse gas (GHG) emissions (IEPR 2018). California's goal is to reduce GHG emissions 40 percent below 1990 levels by 2030 and 80 percent by 2050.

ELECTRICITY AND GAS GENERATION

Electricity generators within the Central Coast region include Diablo Canyon in San Luis Obispo (2,332 MW). In 2016, PG&E announced plans for the closure plan for Diablo Canyon at the expiration of its Nuclear Regulatory Commission operating licenses in 2024-2025 (PGE 2018). Additionally, there are a few small-fired power plants in Santa Barbara, Monterey and San Luis Obispo with a total name capacity of approximately 4,000 MW. Warming temperature is likely to affect the supply of the electricity from gas-fired plants in two ways. One is by reducing generating capacity, and the other is by worsening efficiency through increases in heat rate. These effects are technology specific. For example, Chen et al. (2015) indicate that for combined-cycle and combustion turbine plants, efficiency is reduced by 0.6 and 0.4 percent respectively for each degree F increase in temperature. However, reducing the capacity or efficiency from gas-fired plants might have little impact on the overall power supply to the region if it is connected to the rest of the grid, as those facilities are historically peaking and cycling units. Moreover, CAISO also maintains a healthy reserve margin (NERC 2017).

However, for a baseload unit, the potential inability to generate enough electricity might ripple to the rest of the system. For example, the shutdown of the seaside San Onofre nuclear generating station in San Diego created a supply shortage and was partially responsible for a 59 percent spike in wholesale power prices in the first half of 2013, as well as an increased production cost of $350 million over a 12-month period (Davis and Hausman 2016). As reported, Diablo Canyon frequently cuts its production by as much as 80 percent during storm surges to avoid tripping the units if intake flow is impeded by debris buildup on the intake screens (CEC 2005). Sea level rise would increase both the intensity and frequency of storm surges, thereby exacerbating the situation (Tebaldi et al. 2012).

CLIMATE IMPACTS TO THE ENERGY SECTOR

Higher average temperatures and higher summer peak temperatures will affect energy production, distribution (transmission), and demand. The transmission of electricity is less efficient during hotter periods, leading to electricity deficits especially during peak demand times, with the risk of outages likely to increase. Higher temperatures and intense storm events will also affect energy infrastructure.

Residential electricity demand is also likely to be affected by more frequent heat waves induced by climate change due to the increase in cooling requirements. There are two kinds of measurements of such impacts: short-run and long-run. Short-run impact (also known as intensive margin) holds the capital stock or penetration of air conditioners fixed. The impact on warming weather directly increases the utilization of air conditions, thereby increasing electricity demand. On the other hand, long-run impact (also known as extensive margin) allows long-run adjustment by households to install air conditioners in response to warming weather. Using detailed household billing data, Auffhammer (2017) estimates that, under the RCP8.5 scenario, the extensive margin of the California's Central Coast area is likely to see a 2-6 percent increase in residential electricity consumption during 2080-2099 compared to 2000-2015. The intensive margin is believed to be larger than the extensive margin as newly installed air conditioners are expected to be more energy efficient. His results also suggest that there will be more pronounced increases in electricity demand in inland areas of the Central Coast such as the Salinas Valley, where rising temperatures are projected to lead to increases in peak summer demand and may exceed the capacity of existing substations and distribution circuits

The impact on the natural gas consumption is expected to act in the opposite direction as warming winter weather reduces heating demand. Auffhammer (2017) also reports that, under the RCP8.5 scenario, the residential natural gas demand in California as a whole (not specific to the Central Coast region) is likely to decline by 10.4 percent by mid-century, and then drops by 20.5 percent by the end of the century. The impact on the peak demand is expected to be more profound than other periods.

The power system is also subject to climate change induced impacts from wildfire and SLR. Figure 30 overlays the downscaled wildfire data (Westerling 2017) and sea level rising (1.5 meter elevation) with the power system in the Central Coast Region (Chen and Chen 2018, unpublished data). The risk of wildfire (left) is calculated based on

FIGURE 30

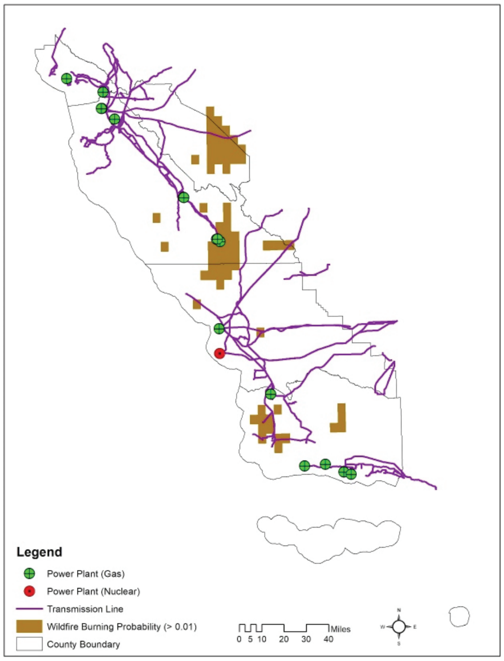


FIGURE 31

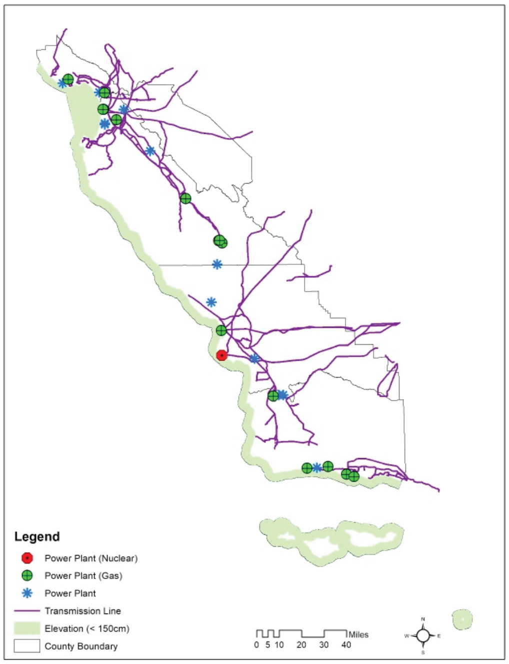


Figure 30 shows risks to the electric system from wildfire; Figure 31 shows risks to the electric system from sea level rise. of wildfire burning. Legend: red- nuclear power plant; green-gas power plant; blue power plant; purple-transmission line.

cumulative probability of simulated burning events to 2099. Figure 30 indicates that a total of 23, 35, 10 and 14 miles-long of power transmission lines and power plants (numbers are within the parentheses) in Monterey (4), Santa Barbara (0), San Luis Obispo (1) and San Benito (0) could be subject to wildfire burning with a probability greater than 1 percent, while the green circles show the number of gas-fired plants subject to the same risk. Figure 31 describes the risk of SLR (1.5 meter) in the region by identifying infrastructure that is 1.5 meter below sea level. Overall, only a small segment of power transmission line in Monterey County (1.35 miles) is subject to the risk of sea level rising. Both figures are based on RCP8.5 scenarios.

While assessing the natural gas sector, new measurements from the Fourth Assessment (Brooks et al. 2018) found that mean subsidence in the Sacramento San Joaquin Delta is around 0.4 to 0.8 inches per year. Together with conclusions from previous studies (based on airborne laser scanning measurements regarding hazards associated with subsidence of the levees), this suggests that sea level rise, shadow water tables induced by sea level rise, and storms could lead to overtopping or failure of the levees, causing damage to the energy infrastructure (Radke et al. 2016, Hummel et al. 2018).

ADAPTATIONS

Scientific studies suggest that the most plausible and cost-effective way to reduce GHG emissions involves deep decarbonization of the electricity-generating sector, electrification of energy services where feasible (e.g. electric heat pumps for space heating, water heating, electric vehicles for transportation), and substantial increases in energy efficiency (Williams et al. 2012, Wei et al. 2013). The electrification of energy services would make electricity the most important energy carrier in California.

Adaptation strategies reflect the "loading order," a state energy policy which calls for meeting new electricity needs: first, with energy efficiency and demand response; second, with new generation from renewable energy and distributed generation resources; and third, with clean fossil-fueled generation and transmission infrastructure improvements. These programs will promote the use of more efficient air conditioning equipment and lighting systems, the increase in the level of insulation (ceiling, floor, and walls), and window glazing used in new and existing homes. To reflect heat, the use of roof materials to reduce the "heat island effect" will be promoted in new construction. Smarter grid technologies aim to improve the ability of the electricity system to respond to peak demands.

Encouraging the development of distributed and centralized renewable resources will also help meet increased energy demand due to climate change. Opportunities to expand renewable distributed generation resources include increased use of solar, biomass (including biomass that is currently being landfilled), and biogas from wastewater treatment plants. Further development of centralized renewable

TAKE HOME MESSAGE

- Residential electricity demand is likely to be affected by more frequent heat waves due to increases in cooling requirements, and warming temperatures are likely to affect electricity supply from gas-fired plants.
- The power system is threatened by wildfire and sea-level rising.
- Adaptations include: energy efficiency, renewable energy, clean fossil-fueled generation, transmission infrastructure improvements, and roof materials to reduce the "heat island effect" in new construction.

resources will help meet expected energy demand due to climate change with care to ensure that associated transmission is developed in the least environmentally sensitive areas.

Transportation and Waste Water

California's infrastructure was developed to accommodate its highly variable climatic conditions, but it is frequently disrupted by natural disasters. Future climate change can directly and indirectly exacerbate these disasters for the Central Coast and add new ones as well, resulting in increased maintenance and repair expenditures, disruptions to economic activity, interruptions to critical lifelines, and impacts to quality of life. The economic cost associated with required alteration, fortification, or relocation of existing infrastructure is likely to be very high.

Transportation is one of three assets the Central Coast Climate Collaborative deemed were of most concern with respect to climate hazards (Wise-West 2017). The main Central Coast transportation infrastructure, including roads, railways, and airports, are vulnerable to climate change. Increased extreme storms, sea level rise, wildfires and potential debris flows will damage roadways and railroads. Extreme hot days will increase the risk of buckling of highways and railroad tracks and may cause premature deterioration or failure of transportation infrastructure, decreasing transportation safety and creating higher maintenance costs. More extreme floods and droughts can cause flooding of tunnels, coastal highways, runways, and railways, in addition to associated business interruptions. Increased wildfires and resulting debris flows are likely to cause more mud and landslides that can disrupt major roadways and rail lines. These disruptions will create greater costs for the state and require more frequent repair.

Sea level rise (SLR) and coastal storm surge increases will dramatically affect transportation routes as well as affect existing fortifications. These will be increasingly inadequate and need to be raised. Areas previously not at risk will become at risk. Union Pacific Railroad (UPR) currently faces potentially several miles of eroded railroad areas in Santa Barbara County. SLR already impacts UPR tracks regularly in Elkhorn Slough where tracks routinely flood during spring tides, slowing or even stopping train traffic at those times. Local bus routes and bus stops will also be affected (County of Santa Barbara Coastal Resiliency Project 2017).

The location of wastewater treatment plants, which are typically sited at low elevations near the coastline, makes them particularly susceptible to coastal flooding. Sea water backflow will impair coastal water sanitation drainage systems during flood events, requiring costly upgrades and alterations. Sewer mains can potentially be impacted by coastal erosion while coastal flooding and erosion could affect parcels that rely on septic systems. These disruptions can also affect service even for those residents who live a safe distance from the coast (Hummel et al. 2018).

Adaptation plans are being developed with estimations of future growth, demand, and vulnerability issues. Proposals include increasing the elevation of streets, bridges, and rail lines, while some at risk sections of roads and rail lines will be relocated farther inland to guard against predicted sea level rise and storm surges. Flood zones will be remapped, and some areas may be identified that will be returned to a natural state.

Box 4: Transportation Adaptation

The California Department of Transportation realigned 2.8 miles of Highway 1 in northern San Luis Obispo county, up to 475 feet inland of the original alignment to protect the route for 100 years from severe coastal erosion exacerbated by climate change. Completed in 2017, the realignment of the highway at Piedras Blancas will also restore the naturalfunctions of the nearby creeks by replacing three crossings with bridges but also remove artificial revetments that will enable bluff and itertidal zones to re-establish equilibrium (Safeguarding California Plan 2018)

Adaptations: Regional, Municipal, Natural Lands

Ruth Langridge, Monique Myers

REGION WIDE

Central Coast Climate Collaborative

In 2017, the region formed the Central Coast Climate Collaborative (CCCC), a membership organization formed to foster a network of local and regional community leaders throughout six Central Coast counties to address climate change mitigation and adaptation. The CCCC includes representatives from Ventura, Santa Barbara, San Luis Obispo, Monterey, Santa Cruz, and San Benito counties as well as stakeholders from local and regional government, business and agriculture, academia and diverse community groups. These members share information and best practices, leverage efforts and resources, and identify critical issues and needs. The CCCC plans to engage communities throughout the region to help ensure a resilient and low carbon Central Coast prepared for climate change impacts. The 6 County Collaborative is part of the Alliance of Regional Collaboratives for Climate Adaptation, a resource hub for adaptation professionals in California. It has developed a mission statement, goals, and an initial list of potential projects for joint development.

Youth Groups

The Central Coast is dotted with small farmworker communities whose residents labor in the fields that produce much of the nation's

FIGURE 32

Youth Action Lab

berries and lettuce. Youth Action Labs organized around the US by the Alliance for Climate Education (ACE) have been a place for students to talk about climate change issues that their community and families already face on a daily basis, and about how climate change impacts the food system and public health (Figure 32). Recognizing that healthy and strong communities begin with appreciation for one's community, the students organized the first ever Central Coast Farmworker Appreciation Day in June 2014. California organizations such as Building Healthy Communities, the Food Empowerment Project, Baktun 12, Alba Farms and Community Food and Justice Coalition collaborated with local community leaders to support the event. Youth, farmworkers, community leaders, local organizations, and businesses joined together to celebrate farmworkers, and provided the opportunity to raise awareness and understanding about the impacts of climate change on our health and well-being. (Center for Climate Change and Health 2018).

Integrated Regional Water Management (IRWM)

Integrated Regional Water Management (IRWM) planning efforts are collaborative efforts to engage in joint planning and project development, making IRWM a good platform for addressing climate change and water issues. Proposition 84/1E IRWM Program Guidelines state that IRWM Plans describe, consider, and address the effects of climate change on their regions and disclose, consider, and reduce when possible greenhouse gas (GHG) emissions when developing and implementing projects. There are 6 IRWM Plans in the greater Central Coast Region, and each involves groups ranging from water districts and agencies to non-profits. The Greater Monterey County region's IRWM Plan, for example, includes 18 members. It has created an initial vulnerability analysis and risk assessment and offers preliminary adaptation measures and climate change mitigation and GHG reduction strategies for the planning region.

Natural Landscapes

Natural landscapes are both the dominant land cover on the Central Coast and an integral component of local communities. They are vital to economies, character and human wellbeing (Balmford and Bond 2005).

The Central Coast is known for its extensive state parks and reserves. Scientists are currently studying the effects of coastal fog on the California Redwood in Big Basin and Landels-Hill Big Creek Reserve in Big Sur (Figure 33). Using laser spectrometers and high-precision sensors, they plan to measure carbon gas (in parts per trillion) to gauge tree health. Data on forest health can then be united with observations of climate-sensitive coastal fog (Bennett 2016).

Central Coast communities have also completed in-depth ecosystem vulnerability assessments including the Goleta Slough Vulnerability Assessment (Revell Coastal 2015), the Morro Bay Sea Level Rise Vulnerability Study (Morro Bay National Estuary Program 2016), and the Santa Barbara Area Coastal Ecosystem Vulnerability Assessment (SBA CEVA) (Myers et al.,2017). Reiter et al. (2015) evaluated effects of adaptation strategies on ecosystem services provided by natural dune and wetland systems, which is aimed at informing local government in Monterey Bay.

FIGURE 33

Redwood trees in Pfeiffer Big Sur State Park.
Source: Vern Fisher - Monterey Herald

Within developed areas, ecosystems are often confined by coastal infrastructure or between the shoreline and infrastructure (i.e. coastal squeeze), making it difficult or impossible for them to move in response to changes in climate and/or sea level. This was evident during the 2015/2016 El Nino when sea level rose 13+cm for six months, providing a window into future sea level rise conditions (Myers et al. 2017). At Goleta Beach Park, severe erosion occurred, threatening the grassy recreation area and parking lot. An emergency permit was obtained to armor the beach with riprap. While the grassy park was protected, armoring resulted in loss of dry sandy beach, the upper beach ecosystem, and beach access (Figure 34).

FIGURE 34

Goleta Beach during the 2015/2016 El Nino.
Source: Monique Myers

Strategies for protecting natural lands include:

- Allowing space for inland migration of wetlands and beaches (including establishment of inland migration corridors).
- Restoring wetlands and dunes.
- Removing vulnerable structures rather than armoring shorelines.
- Implementing 'soft' nature-based shoreline protection solutions.
- Reducing beach grooming to restore biodiversity and allow formation of dunes, which are natural barriers to storms.
- Releasing sand from streams and watersheds, including removal of shoreline armoring and dam removal.
- Adding a thin layer of sediment to raise marshes (Climate Readiness Inst. 2018).
- Shifting community development inland (Salado and Martinez 2017).
- Developing landscape scale conservation plans including local knowledge (Filho et al. 2018).

Natural approaches to ecosystem adaptation, including some of the above options, have been successfully demonstrated at a variety of sites in California (Judge 2017) and are currently being considered for the Central Coast. Just south of the Central Coast in Ventura, managed retreat is occurring at Surfer's Point where removal of a bike path and parking lot allows space for inland migration of the beach. Other on-the-ground community-scale physical adaptation projects include: Devereux Slough restoration; Elkhorn Slough restoration; Groundswell Coastal Ecology coastal restoration (Seabright Beach & Natural Bridge); Salinas River State Park sand dune restoration; San Lorenzo River channel flood improvement; and Santa Barbara County debris basin removal and fish passage project (Climate Readiness Institute 2018).

MUNICIPAL AREAS

Sea level rise and storm impacts to Central Coast communities include: flooding, erosion, and damage to buildings and infrastructure. Coastal buildings and infrastructure that are located close to sea level (e.g. Santa Barbara airport, wastewater treatment facilities) or near the top edge of receding bluffs are particularly vulnerable.

A Climate Risk Analysis for the broader Monterey County area noted that coastal storm flooding will lead to inland flooding, eventually threatening crops in the Salinas Valley. Inundation will occur mostly in wetland areas by 2030, but by 2060 flooding will begin to impact developed areas. Peak flooding will impact coastal assets (e.g. storm drains, culverts and tide gates, groundwater wells Moss Landing Harbor, dunes, beach, wetlands), and work is underway to assess and implement adaptation strategies (Greater Monterey IRWM Regional Water Management Group Meeting 2018)

FIGURE 35

Aerial image of Shoreline Park in Santa Barbara. This long narrow park provides a buffer against coastal erosion for the Santa Barbara Mesa community. Source: Google Earth

There are also examples of shoreline segments within municipalities that are well prepared for climate change impacts. For example, the City of Santa Barbara's Shoreline Park occupies a long, narrow parcel of coastal land on top of receding bluffs. The park acts as a buffer to coastal erosion for inland homes and infrastructure, allowing for inland migration of the bluffs, while providing for public recreation and access to the coast (Figure 35). Other larger areas of coastal open space that buffer populated coastal areas include the Douglas Family Preserve in Santa Barbara, Ellwood Mesa Open Space in Goleta, and Fiscalini Ranch Preserve in Oceano.

To estimate future exposure of homes, businesses, and infrastructure, multiple storm and sea level rise scenarios are available from the USGS Hazards Exposure Reporting and Analytics (HERA) application for the entire Central Coast. Scenarios of coastal hazards and shoreline change are modeled by the USGS Coastal Storm Modeling System (see Physical Impacts of Climate Change Section).

Several reports have identified communities that are more vulnerable to sea level rise and more extreme storms, including SLOC's Preliminary Climate Change Vulnerability Assessment for Social Systems, CDPH county – level Climate Change, and Health Profile reports, while the City of Santa Cruz is developing a Social Vulnerability to Climate Change Analysis (Climate Readiness Institute 2018).

Spurred by the California Global Warming Solutions Act (AB32) and with tools (i.e. Climate Action Resource Guide for Local Governments) and guidance from the State-level (e.g. California Coastal Commission's 'Residential Adaptation Policy: Interpretive Guidelines for Addressing Sea Level Rise in Local Coastal Programs), Central Coast cities and counties are assessing climate vulnerabilities and engaging in climate adaptation planning. Climate Action Plans (CAPs) have been developed focused on GHG reductions, and Local Coastal Plans (LCPs) have been certified for all Central Coast counties and most cities (CA Governor's Office of Planning and Research, 2016). Central Coast cities and counties have developed sea level rise, climate, or coastal hazards vulnerability assessments and other relevant substantial plans or reports (Climate Readiness Institute 2018). Several are listed below (for a complete list: CCC, 2016 pp.6-7).

Santa Barbara

- Sea Level Rise and Vulnerability Study
- Climate Action Plan
- Sea Level Rise and Coastal Hazards Vulnerability Assessment
- Coastal Ecosystem Vulnerability Assessment (SBCEVA)
- Santa Barbara County Coastal Resilience Project

Santa Cruz

- Coastal Climate Change Vulnerability Report
- Climate Action Plan
- Climate Action Strategy

San Luis Obispo County

- Integrated Climate Change Adaptation Planning in SLOC
- SLOC Energy Wise Plan – Chapter 7
- Climate Change Vulnerability Assessment for Social Systems
- Projected Future Climatic and Ecological Conditions in SLOC

Monterey

- Sea Level Rise and Vulnerability Analysis
- Economic Impacts of Climate Adaptation Strategies for S. Monterey Bay
- Evaluation of Erosion Mitigation alternatives for Southern Monterey Bay
- The Nature Conservancy Coastal resilience Project for Monterey Bay

Goleta

- Coastal Hazards Vulnerability and Fiscal Impact Report
- Sea Level Rise Management Plan for Goleta Slough

Oxnard

- A Sea Level Rise Atlas for the City of Oxnard

Pacific Grove

- Climate Change Vulnerability Assessment

There are also sub-region studies focused on specific assessments. Examples include: Central Coast Wetlands Group's vulnerability assessments for jurisdictions in the Monterey Bay area, which estimates coastal climate hazard zones and exposed wetlands, critical facilities, property, and infrastructure (units and value) (Wise-West 2017), and City of Santa Cruz, which addresses impacts from sea level rise (Table 9). Additionally, the Monterey Bay Regional Climate Action Compact is beginning to expand from emissions mitigation to a focus on adaptation (Wise West personal communication 2018). Completed projects include: all San Lorenzo River bridges raised (except Hwy 1 bridge and train trestles), relocation of the Emergency Operations Center, and others which are still in progress (e.g. coastal re-vegetation) (Wise-West 2017).

TABLE 9: CITY OF SANTA CRUZ: CLIMATE CHANGE HAZARDS AND IMPACTS

COASTAL	NON-COASTAL
Erosion (Sea Level Rise)	Increased Wildfire Threat
Rising Tides (Sea Level Rise	Increased Landslide Potential
Coastal Storm flooding (Sea Level Rise)	Extreme Storms and Droughts
Salt Water Intrusion	Increased Temperatures

Coastal Communities and Sea Level Rise

Documents recently developed or completed that address local government climate adaptation include: the California Coastal Commission's Residential Adaptation Policy Guidance (2018), the draft Safeguarding California Implementation Plan 2017 Update, the California Coastal Commission Statewide Sea Level Rise Vulnerability Synthesis (2016), and an updated California Adaptation Needs Assessment Survey (In progress).

TAKE HOME MESSAGE

- Significant efforts to assess and adapt to climate change are occurring.
- Community efforts include for example, the Central Coast Climate Collaborative involving cities, counties and community groups, and the Central Coast Action Lab focusing on youth in farmworker communities.
- Many cities counties, NGOs and colleges have completed assessments of local vulnerabilities and engaged in climate adaptation planning.
- Some undeveloped lands are undergoing vulnerability assessments and there are on-the-ground adaptation projects being implemented.

Native American Lands

Tribal communities are particularly vulnerable to increasing weather and climate extremes as they rely on the land for economic development, sustenance, and the maintenance of cultural traditions. Changes to natural systems impact Tribal communities more directly than the general population. Moreover, limited resources hinder adaptations and treaty rights that restrict movement mean that relocation to new areas to accommodate climate shifts is not a viable option. Drought is a pervasive climate-induced weather impact as water is at the heart of many Tribal cultures and the foundation of their lifestyles. Wildfires and flooding also pose significant risks. Extreme events are endangering wildlife and their habitats.

In 2010, Tribal organizations began to develop a national Tribal natural resource strategy for conserving Tribal lands, wildlife, and natural and cultural resources (Natural Wildlife Federation 2011).

FIGURE 36

Residential Solar Installation. Source: SYCEO

The Santa Ynez Band of Chumash Indians have taken numerous steps to reduce greenhouse gas emissions and address the impacts of climate change on tribal peoples, land, and resources. The Santa Ynez Chumash Environmental Office (SYCEO) addresses tribal environmental issues, including a strong focus on climate change mitigation. One program is aimed at increasing home and commercial building energy efficiency throughout the reservation, as well as training community members to install solar panels and assess and upgrade buildings for increased energy efficiency. They have already facilitated 5 residential solar installations, 16 Home Energy Assessments and 2 home retrofits (Figure 36). With a strong focus on habitat management and restoration, the SYCEO has developed a database of native and culturally important plant species. As of 2013, this database includes over 320 plant species. Additionally, in collaboration with the Bren School of Environmental Science and Management at the University of California Santa Barbara (UCSB), the SYCEO created models that project climate change's effects on sea levels and native plant populations in Central California (http://www7.nau.edu/itep/main/tcc/Tribes/sw_chumash).

The Amah Mutsun are committed to "incorporate adaptation strategies that address climate change and promote resilience for humans and native species alike" (http://amahmutsun.org/wp-content/uploads/2014/09/General-Info-Sheet.pdf). They are currently seeking to adapt their knowledge to the hotter and drier conditions projected under climate change. Traditionally, they left plants in areas where they were naturally found and dug bulbs for food to encourage bulblets to form, or they loosened the soil ahead of rhizomes and roots. Today, they are working with climate scientists and incorporating climate projections to find better growing conditions to enable plants to adapt faster than they could adapt on their own. Additionally, prescribed burns are being utilized to clear forest underbrush and leave mature trees to reduce the risks of the more intense wildfires predicted by climate change (Takemura 2016).

In addition to the above, more details can be found in a companion Fourth Assessment report which explores how tribal communities – both in Santa Barbara and statewide – are threatened by and adapting to the threats posed by climate change (Tribal and Indigenous Communities Summary Report, 2018).

TAKE HOME MESSAGE

- Tribal communities have implemented multiple projects to reduce greenhouse gas emissions and address the impacts of climate change on tribal peoples, land, and resources.
- A companion Fourth Assessment report exploring how climate change will impact Tribal and indigenous communities (and how these communities are leading adaptation efforts) can provide further information and case studies.

CASE STUDY: THOMAS FIRE

Jason Kreitler, Joel B. Sankey, Amy East, Christina (Naomi) Tague

THE THOMAS FIRE

The Thomas Fire ignited in Ventura County, CA, under red flag wind conditions on the evening of December 4th, 2017, and grew quickly to over 63,000 acres (25,500 ha) by the end of December 5th (Figure 37). Some 39 days later, when the fire reached full containment, it had burned more than 281,000 acres (114,000 ha), making it the largest fire in California's recorded history and the seventh most destructive in terms of structure losses. Affected areas included incorporated and unincorporated areas of Ventura County, and the larger towns of Ojai, Ventura, Carpinteria, Montecito, and the City of Santa Barbara (State of California 2018). California and Presidential Disaster Declarations were designated in December and January, respectively.

FIGURE 37

Thomas Fire. Source: Mike Eliason, Santa Barbara County Fire Dept.

The Thomas Fire occurred during an extensive late-season Santa Ana wind event and before the overdue first rains of the season had arrived, and both factors contributed to the fire's historic proportion. In January 2018, high-intensity rains over the burned area caused large debris flows in the drainages upstream of the town of Montecito, leading to 21 deaths and causing millions of dollars in additional damages to an area already struck by disaster.

The events and conditions of the Thomas Fire did not occur in isolation; much of California experienced a very active fire year in the summer and fall with record hot temperatures, high winds, and low fuel moisture content that followed a wet winter in 2016/17 which produced extensive fine fuels from grass and brush. California had also recently experienced

THOMAS FIRE, CONT'D.

the greatest period of drought on record (Robeson 2015, Diffenbaugh et al. 2015). The Thomas Fire occurred recently enough that only initial results are available to assess the factors that contributed to the fire and its effects. However, it is useful to begin to consider whether the Thomas Fire and its aftermath were typical, albeit much more extreme, relative to wildfires and post-fire effects in the region, or if they could be representative of future devastating fires and post-fire effects under climate change.

A primary precursor to the conditions that set up the Thomas Fire was the state's recent and historic drought. Observed precipitation during 2012 - 2016 was the lowest on record. After a short reprieve from drought conditions during the wet winter of 2016/17, weather in 2017 again returned to warm and dry prevailing conditions, including record high temperatures in the summer before the fire occurred in December 2017. It quickly grew due to strong, dry, offshore Santa Ana winds originating from regions of high pressure over the Great Basin and Mojave Desert. The Santa Ana winds are often responsible for the growth of large fall wildfires in Southern California (Westerling et al. 2004, Moritz et al. 2010). The Thomas Fire occurred in an area near the geographic boundary between Southern California and the Central Coast, where differences with respect to fire regimes and weather conditions exist. What was unusual about the conditions leading to the Thomas Fire was the later than usual onset of both the Santa Ana winds and the rainy season, and it was unprecedented that such a large fire burned in December and January. The fire consumed chaparral and coastal sage scrub vegetation and continued to expand rapidly irrespective of suppression resources.

On December 10th, the fire had consumed a cumulative 230,000 acres and made another large run westward in the rugged mountains above Carpinteria. At that point, the rate of expansion declined, and full containment was reached on January 12, 2018. In sum, the fire burned over 281,000 acres (113,700 ha), more than any other in California's modern recorded history. It destroyed 1,063 structures and left an additional 280 damaged. Two fatalities occurred during the fire: a firefighter succumbed to injuries from active firefighting, and an evacuee died in a car accident. At its peak, the fire involved over 8,500 firefighters and final estimates of suppression efforts, while still forthcoming, will likely exceed $177 million dollars. Full economic damages are not yet available, but given the magnitude of evacuation, structure loss, damages, and business interruption, the Thomas Fire will surely have a large economic cost for individuals, the region, and California.

THOMAS FIRE, CONT'D.

MONTECITO DEBRIS FLOWS

In early January 2018, merely a month after the Thomas Fire began, intense rainfall struck the Southern California coastal community of Montecito and its surrounding region, causing devastating debris-flow activity (Figure 38).

FIGURE 38

Montecito Hills Debris Flow. Photo: Jason Kean, USGS

Surficial geology in the Montecito area consists of gently sloping alluvial fans at the outlets of steep canyons, which were evidently deposited by debris flows during storm events over the past several thousand years, and so the debris-flow hazards so apparent in January 2018 represented neither an unexpected nor a one-time occurrence (Keller et al. 1997, Minor et al. 2009). Rainfall intensities reached as high as 0.54 inches (1.37 cm) in just 5 minutes as recorded at Montecito on January 9th, 2018, an intensity estimated to occur only once every 200 years based on existing records. In nearby Carpinteria, 0.86 inches (2.18 cm) of rain fell in 15 minutes on the same evening , equivalent to a 50-year recurrence-interval event. The National Weather Service reported maximum rainfall intensities for this event to be equivalent to 6.48 in/hr (165 mm/hr) for the 5-minute duration rainfall, and 3.44 in/hr (87 mm/hr) for the 15-minute duration rainfall (State of California 2018). These observed rainfall rates substantially exceeded the empirical thresholds for rain intensity and duration above which widespread regional landsliding and debris-flow formation will occur (e.g., Cannon 1988, Cannon et al., 2008). Consequently, large and abruptly activated debris flows and hyperconcentrated sediment flows were triggered in the steep, mountainous watersheds immediately above Montecito.

The severity of debris flows as a result of this intense rainfall may have been worsened by the rainfall occurring so quickly after the Thomas Fire. The Thomas Fire was unusual in occurring so late in the year, more than two months into the start of the water year, during a season when late fall and winter rains have typically already begun to promote

THOMAS FIRE, CONT'D.

vegetation regrowth after fires that might have provided some additional slope stability. The extremely low permeability and hydrophobicity of the burned ground surface on the hillslopes burned in the Thomas Fire is considered a major contributing factor to the formation of debris flows that devastated Montecito (State of California 2018). Unlike debris flows that form due to excess pore pressure in surface materials caused by rain falling on already saturated ground (as in the January 1982 storm in the Santa Cruz Mountains(Coats 1985), the formation of major debris flows in Montecito on January 9th, 2018 was likely attributable almost entirely to the intense rain having fallen on unsaturated but recently burned ground (State of California 2018, J. Kean, U.S. Geological Survey, pers. comm).

Initial findings from the Montecito debris-flow events of January 2018, based on field reconnaissance and aerial photography (J.A. Warrick and J. Kean, U.S. Geological Survey, unpublished aerial images) indicate that additional unconsolidated sediment remains in some of the steep stream channels upstream of the Montecito region. These unvegetated sediment deposits, which appear to be several meters thick, seem to have recently eroded from the hillslopes above, likely as a result of the combined fire and intense rainfall effects, and it is reasonable to expect that they could serve as a source of additional sediment washing downstream into the more urbanized and developed regions over the coming months and years, with the rate of sediment transport out to creek mouths and the coastal zone to be determined by future rainfall conditions. The debris-flow risk will remain elevated for 2–5 years following the Thomas Fire (State of California 2018). It is noteworthy that several previously constructed debris-flow dams (i.e. human-made sediment retention structures) were in place during the Montecito events in anticipation that such an event could occur, with these dams built to reduce sedimentation effects on downstream channels. Some of these sediment retention basins were entirely filled with sediment during the January 2018 debris-flow events, and new sediment was consequently delivered to the beach and nearshore zone.

The effects of the newly delivered sediment in the coastal zone, and any potential contaminated material that may be adsorbed onto that sediment, on human or ecosystem health in the coastal zone are as yet undetermined. Following wildfire and debris-flow events, one particular concern is the introduction of contaminants such as polycyclic aromatic hydrocarbons (PAH) to the downstream and marine environment; such PAH contaminants can affect the immune systems and reproductive capabilities of fish and other organisms (Incardona et al. 2004, Conaway et al. 2013). Portions of the Thomas Fire burn area also included naturally occurring hazardous minerals, including cadmium, selenium, and uranium; a small portion of the burn area within the Los Padres National Forest is thought to contain naturally occurring asbestos, and it is not known whether asbestos-formed minerals may have been transported downstream during post-fire sediment transport (State of California 2018). The potential effects of contaminant transport that follows from fire and flood events such as occurred in Southern California in 2018 remain to be assessed.

THOMAS FIRE, CONT'D.

Impacts on the Human Community

The Montecito debris flows originated from watersheds that form San Ysidro, Romero, and Montecito Creeks. This area has a stark elevation gradient as the steep Santa Ynez Mountains quickly transition to foothills and alluvial fans that meet the Santa Barbara Channel. Land use in the foothills and below is almost entirely low to medium density residential development, and houses are located in close proximity to the creeks and drainages of the region. In most cases, the debris flows followed these primary creeks and traveled to the alluvial fans, reaching the ocean in some areas (Figure 39). Almost all of the 129 destroyed residences, 307 damaged residences, and 21 fatalities occurred near these primary creeks, according to observer data and locations gathered by the Santa Barbara Independent. As of April 2018, warnings and evacuations were continuing for the impacted area with each approaching storm.

FIGURE 39

Montecito Debris Flow. Photo: Mike Eliason, Santa Barbara County Fire Department

In addition to the tragic loss of life and property, the debris flows caused tremendous business and transportation interruptions. Highway 101, an iconic arterial of California, was blocked for many days, as was the adjacent Surfrider railroad line. The communities of Santa Barbara, Montecito, and others in the region are heavily influenced by tourism that relies on connectivity. Similarly, thousands of commuters from points further south were unable to travel to their jobs in Santa Barbara and the surrounding region.

In the wake of this disaster, many questions are being asked regarding emergency management, evacuation orders, communication, and the use of science in decision-making. Suffice to say, this situation must be seized upon to learn as much as possible and prevent the future loss of life to disasters such as these.

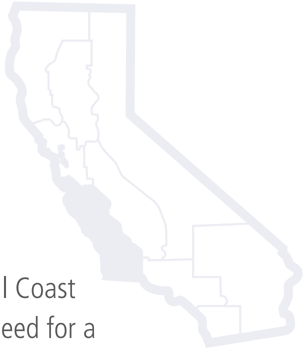
THOMAS FIRE, CONT'D.

FUTURE INSIGHTS

Climate change and anthropogenic influence are expected to increase wildland fire activity and post-fire effects across much of the Western USA, including regions of California (Westerling et al. 2006, Abatzaglou and Williams 2016, Sankey et al. 2017). In many of those regions, climate change is projected to lead to increases in the size and severity of wildfires due to increased temperatures and drought. However, the vegetation of California's Central Coast is a fire-dominated ecosystem in which fires occur in periods of non-drought and drought, and regularly impact vegetation and reduce vegetation cover. Therefore, the effect of climate change on fire in the Central Coast of California may be more uncertain compared to other regions of California (described in the Wildfire and Post Wildfire Impacts section of this report and in Mann et al. 2016). For example, prolonged drought and higher temperature could ultimately reduce fire severity in the southern Central Coast due to fuel limitations. A longer drier fire season, however, could increase frequency and severity in the wetter more northern parts of the Central Coast.

While the impact of climate change on fire frequency and size for the Central Coast is uncertain, there remains a high likelihood that large, high severity fires will continue to occur for the next decades throughout this region. The social costs of the Thomas Fire were also particularly high due to the subsequent debris flow. Given that precipitation intensity is likely to increase with climate change (Trenberth 2011), the likelihood of post-fire flooding, debris flow, and associated losses will also increase.

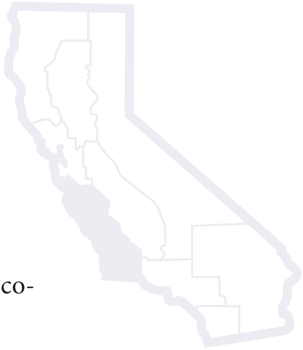
California has a growing problem with climate change related hazards and increasing exposure as population growth and housing developments expand the wildland urban interface. This problem is multifaceted, as housing growth adds exposure but also increases the rate of ignitions, increasing the likelihood of fire independent of other factors (Syphard et al. 2017). This is particularly true for the Central Coast, given its desirable Mediterranean climate, scenic beauty, and expectation for continued development and population growth.



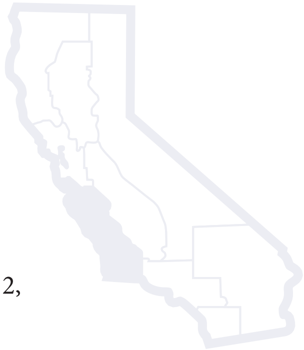
Knowledge Gaps and Potential Future Projects

While significant research is continuing on the scientific impacts of climate change and the Central Coast is actively involved in mitigation and adaptation projects, there is more to be done including a need for a better understanding of:

- Orographic climate effects which are critical to representing temperature and precipitation, among other variables, in the Central Coast Region, using the next generation of climate model projections that will likely be able to incorporate increased spatial resolution.
- The extent to which fog influence will change over the coming decades.
- The interplay between present and future drought and wildfires and precipitation-triggered landslides and mudflows is a significant threat to coastal communities, but poorly understood. A robust, state-of-the art assessment of future coastal hazards will be completed for the entire Central Coast in early 2019 by the USGS.
- How complex changes in the Central Coast landscape – through urban development, changing vegetation communities, and changing fire regimes – are interacting with changing storm frequencies and intensities to alter storm event runoff production and the sediment and nutrients that runoff carries with it.
- How changes in post-fire vegetation recovery with a changing climate will alter fuel and fire regimes in semi-arid, Mediterranean ecosystems of the Central Coast, and how Santa Ana winds, a major driver of fire intensity and fire size in this region, will change with climate.
- How maritime-climate influences in the narrow coastal band, which are swamped by inland patterns, will be impacted by climate change such as maximum temperature increases.
- How species respond to climate change beyond short-term physiology of some groups, as well as the effects of climate (both means and variation) on demography, genetics, and biotic interactions, as well as the potential for plasticity vs. evolutionary responses.
- How changing climate will affect fire, precipitation, and subsequent post-fire debris flow hazards, and how these hazards will interact with increases in population and land use change to affect the vulnerability of communities on the Central Coast and beyond.
- How sediment dynamics will respond to future extreme hydroclimatological variability.
- How salt deposition from near-shore geo-engineering schemes (e.g. solar radiation management by saltwater spray) will affect coastal redwood forest and agricultural ecosystems.
- More data to assess the potential risk posed from mega-droughts (such as the 2012-2016 drought) on extirpation risk for reptiles, amphibians, and other wildlife.
- How environmental factors create "good flower" years to enable a more robust prediction of their persistence in the future.
- The extent to which higher temperatures and an earlier end to the rainy season will shorten the growing season and reduce seed production of invasive grasses versus native forbs and grasses.



- How the influence of climate related flow extremes influences the ecological integrity of food webs and eco-services (water supply, quality, and support of fisheries), and how flow variations interact with land use development and stream biodiversity.
- When and where habitat and ecological communities are deteriorating, and what improvements are occurring as a consequence of watershed-scale protections of water quantity, quality, and flow regime.
- The effectiveness of alternative water management approaches to increase drought resilience to reduce water shortages on the Central Coast.
- More effective natural approaches to climate adaptation.
- More targeted outreach and engagement with the public (especially vulnerable communities and in converting climate awareness to action) and integration of work between sectors.



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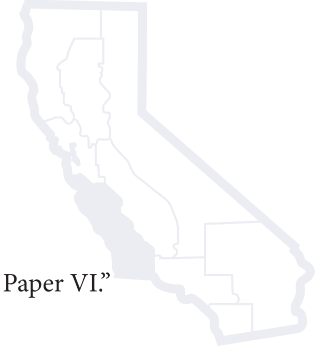

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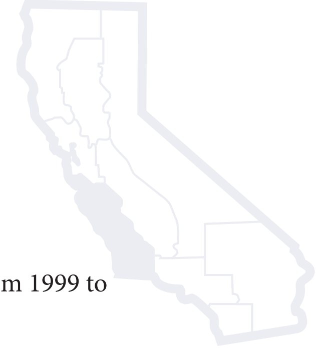

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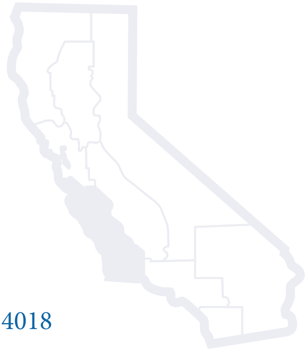

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