CALIFORNIA'S FOURTH
CLIMATE CHANGE
ASSESSMENT

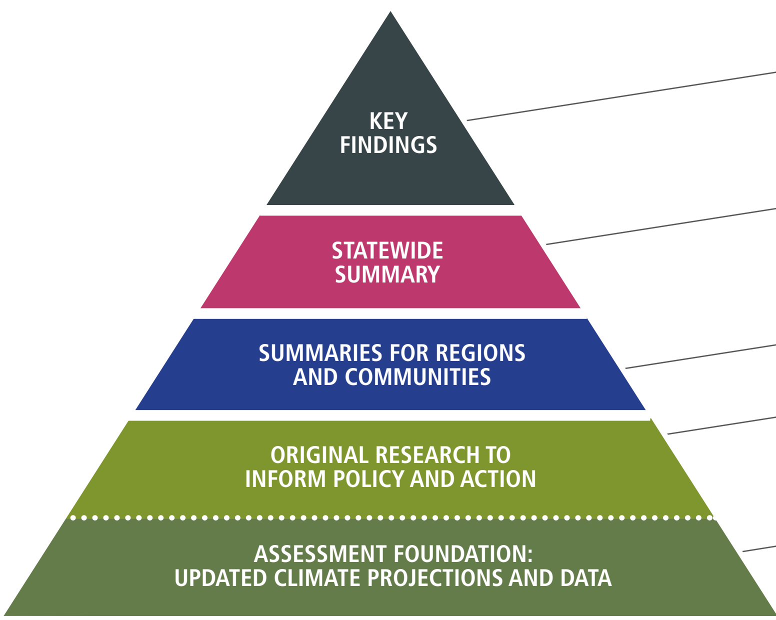
North Coast Region Report

Coordinating Agencies:

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

CALIFORNIA'S FOURTH
CLIMATE CHANGE
ASSESSMENT

North Coast Region

The North 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 North 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 North Coast Region from climate change.

CALIFORNIA'S FOURTH
CLIMATE CHANGE
ASSESSMENT

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Highlights

The North Coast region is notable for its extensive natural ecosystems, abundance of water, and rural character. In some ways, these characteristics make the region less vulnerable to climate change impacts than other parts of California. Higher annual precipitation and lower human water demands mean less social disruption during drought. Cooler overall temperatures limit public health risks associated with heat waves. The rugged and largely undeveloped coast line offers greater opportunity to accommodate sea-level rise than coastal regions to the south. In other ways, however, climate change represents a significant threat. Many of region's native plants and animals, including endangered plant, wildlife, and fish species, are dependent on the cool, wet conditions that characterize coastal forests and river corridors. As the climate warms and precipitation patterns change, these important habitats may shift or disappear from the landscape. The distributed, rural population faces growing threats from natural disasters – including wildfire, flooding, and landslides – that put property, critical infrastructure, and life at risk. The region's low population and limited economic base make it difficult to secure funding for needed disaster preparedness and response systems and for infrastructure investments needed to reduce climate change vulnerabilities. Nevertheless, novel community-based efforts, involving partnerships between state and federal agencies, local and regional governments, tribes, and NGOs, are implementing a variety of adaptive measures to improve the resilience of the region's ecosystems and communities to climate change.

This report summarizes major climate change risks for communities and natural resources in the North Coast region of California, encompassing Mendocino, Humboldt, Del Norte, Lake, Trinity and Siskiyou Counties. The synthesis report identifies several key climate change effects for the region, including:

- Average annual maximum temperatures are likely to increase by 5-9 °F throughout the region through the end of the 21st century. Interior regions will experience the greatest degree of warming.
- Annual precipitation is not expected to change significantly, but will likely be delivered in more intense storms and within a shorter wet season. As a result, the region is expected to experience prolonged dry seasons and reduced soil moisture conditions, even if annual precipitation stays the same or moderately increases. Less precipitation will fall as snow and total snowpack will be a small fraction of its historical average.
- There is a higher likelihood of extreme wet years and extreme dry years (drought). An "average" rainfall year will become less common.
- A rise in extreme precipitation events will increase the frequency and extent of flooding in low-lying areas, particularly along the coast where flood risk will be enhanced with rising sea levels.
- Streamflows in the dry season are expected to decline and peak flows in the winter are likely to increase.
- Sea-level rise projections differ along the coast, but are greatest for the Humboldt Bay region and Eel River delta, threatening communities, prime agricultural land, critical infrastructure, and wildlife habitat.
- Wildfires will continue to be a major disturbance in the region. Future wildfire projections suggest a longer fire season, an increase in wildfire frequency, and an expansion of the area susceptible to fire.

These changes will have significant consequences for natural ecosystems, working landscapes, and the built environment. These include:

- Habitat loss for sensitive plant and wildlife species, including cold-water fish species such as salmon.
- Change in vegetation types, including forests.
- Reduced productivity of rangeland and pastureland.
- Increased flood and landslide risks to critical infrastructure, including major transportation corridors, water supply systems, wastewater treatment plants, and energy and communication networks.
- Increased public health risks from wildfire, floods, heat waves, and disease vectors. These risks are greatest for vulnerable populations along the coast and in remote inland communities.

A few of the recommended climate adaptation options include:

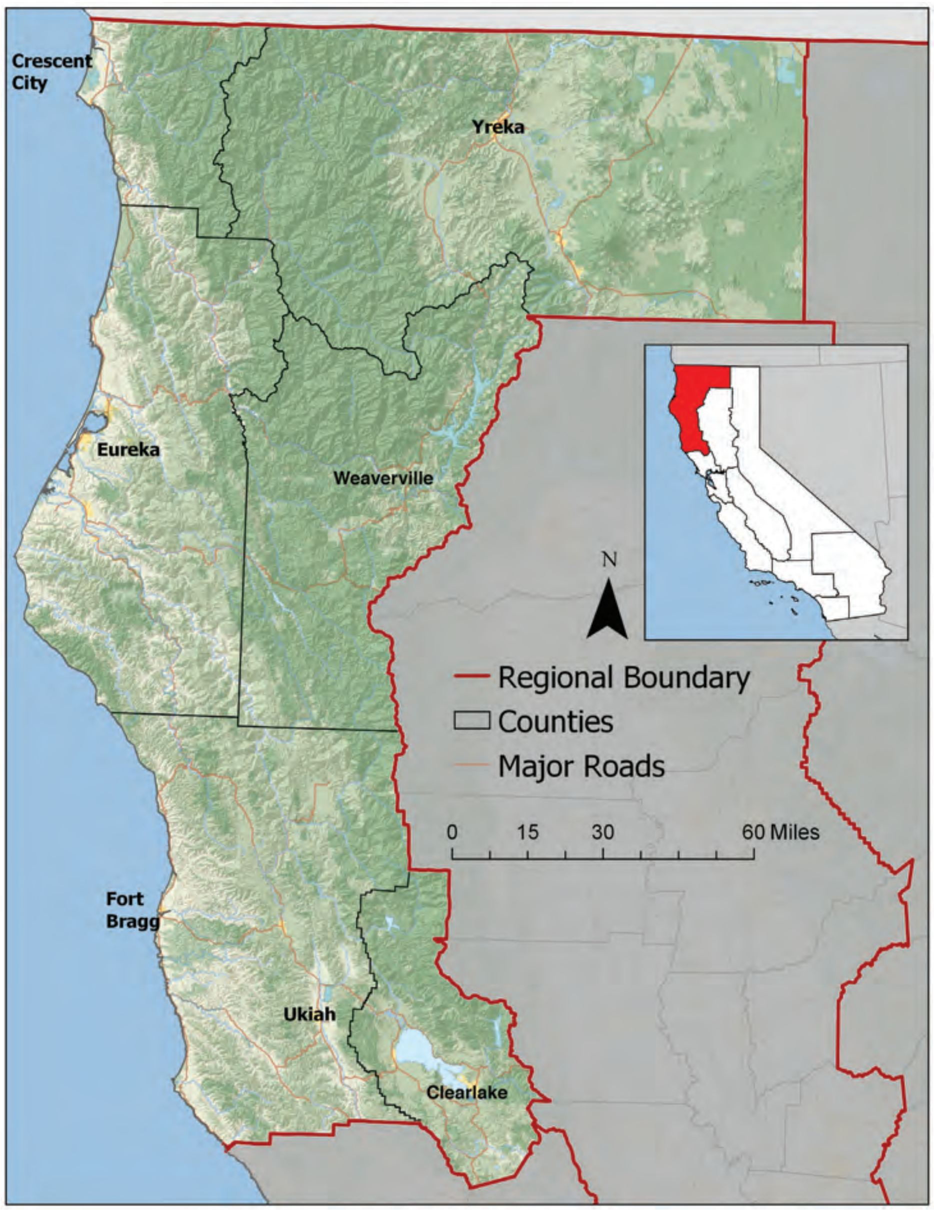
- Protection of climate refugia and migration corridors for wildlife and freshwater species.
- Habitat preservation and restoration, particularly in river, riparian and wetland systems that support high species diversity and cold-water species.
- Fire management, including fuel load reduction by harvest in forests and prescribed fire in forest, woodland, and rangeland systems.
- Short- and long-term planning and investment in transportation, water, and energy infrastructure system resilience, particularly in coastal zone.
- Investment in emergency planning and response systems.

Expanding opportunities for stakeholder participation in planning processes and development decisions is critical for raising awareness of climate risks, building a common understanding of vulnerabilities, and allowing local perceptions and preferences to guide adaptation strategies. Overall, strengthening of community-based research and partnerships will help to advance understanding and to limit the impacts of climate change on North Coast communities, ecosystems, and livelihoods.

Introduction to the North Coast Region

This report summarizes major climate change risks for communities and natural resources in the North Coast region of California, encompassing Mendocino, Humboldt, Del Norte, Lake, Trinity, and Siskiyou Counties (Figure 1.1). We synthesize recent scientific information on climate change from the peer-reviewed literature, government documents, and reports from California's Fourth Climate Assessment (Fourth Assessment), addressing impacts to ecosystems, working landscapes, and communities in the region. We also identify examples of adaptation strategies to avoid or limit the adverse effects of climate change. We first review the state-of-the-science on our understanding of historical and projected changes in regional climate patterns. We next address the impacts of climate change to ecosystems, natural resources, and working landscapes and then evaluate vulnerabilities of communities to climate change, including threats to critical infrastructure, public health, and cultural resources. The last section of the report identifies information gaps and priority research topics to improve our ability to adapt to climate change impacts in the North Coast region. This report is one of nine regional studies in the Fourth Assessment.

FIGURE 1.1



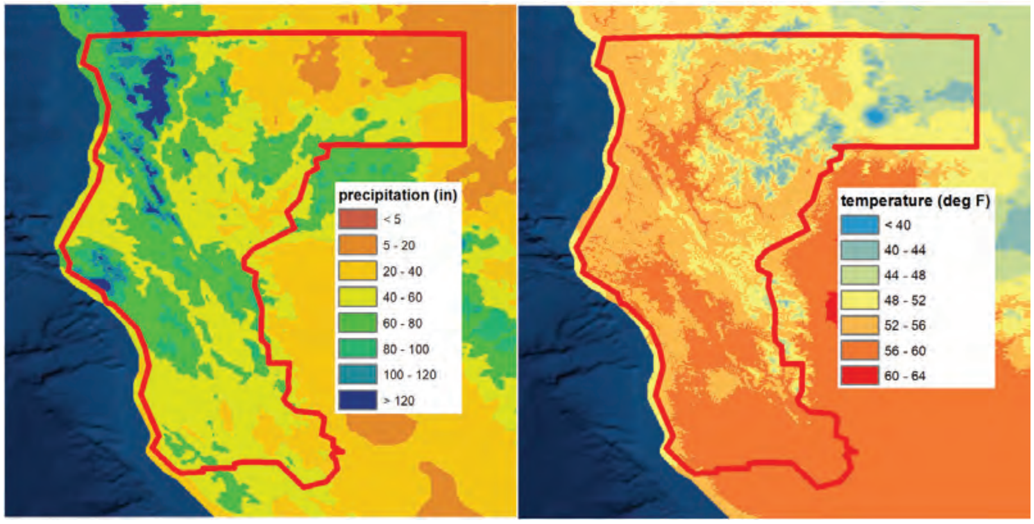
The North Coast is best known for its rugged coast, Humboldt Bay and lagoons, redwood forests, wild and scenic rivers, iconic salmon and steelhead, and diverse natural landscapes. This sparsely populated region encompasses 11.5% of the state by area, but supports less than 1% of its population (**Table 1.1**), most of which is concentrated in cities and unincorporated communities around Humboldt Bay (pop. 80,000), including Eureka (pop. 27,000) and Arcata (pop. 17,000), in other parts of the coast (Fort Bragg, pop. 7,000 and Crescent City, pop. 7,500), and along the Highway 101 corridor (Ukiah, pop. 16,000). The North Coast is also home to many Native American tribal communities that inhabit ancestral lands along the coast and throughout the interior zone of the region, including 37 federally recognized tribes (California Department of Water Resources 2013a). About 6 percent of the region's residents identify themselves as tribal members according to the 2017 US Census Bureau estimates, compared to only 1 percent statewide.

TABLE 1.1

	POPULATION	AREA(MI²)
Mendocino	87,628	3,506
Humboldt	136,646	3,568
Del Norte	27,540	1,006
Lake	64,116	1,256
Trinity	12,782	3,179
Siskiyou	43,603	6,278
Total	**372,315**	**18,793**
% of State	*0.9%*	*11.5%*

North Coast study region, encompassing Mendocino, Humboldt, Del Norte, Trinity and Siskiyou Counties.

FIGURE 1.2



North Coast Region precipitation and temperature, observed 30-year average from 1981-2010 (Source: PRISM Climate Group 2018).

The North Coast region is the wettest part of California and receives 55 inches of annual precipitation on average (1981-2010). The regional climate exhibits distinctive, Mediterranean-type seasonality in which most precipitation falls between November and April, followed by a prolonged dry season from May through October. The climate is also characterized by high inter-annual variation in precipitation. Most precipitation is delivered by large storms that track eastwards from the Pacific Ocean, resulting in much wetter conditions along the western California Coast Range relative to interior areas (**Figure 1.2**). The Pacific also moderates summer and winter temperatures along the coast, which generally range from the low-30s (°F) in the winter to mid-80s in the summer, whereas temperatures interior to the Coast Range often fall below 30 in the winter and exceed 100 °F in the summer.

Most of the region's precipitation drains into large coastal rivers, including the Smith, Klamath-Trinity, Mad, Eel, Mattole, and Russian Rivers. The southeast corner of Siskiyou County lies within the upper Sacramento River watershed[1]. Runoff also flows into Clear Lake, the largest natural freshwater lake wholly within California. The study region largely overlaps with the California Department of Water Resource's (DWR) North Coast Hydrologic Region, which produces over 40 percent of the state's total natural runoff (DWR 2013a). The largest reservoir in the region is Trinity Lake (~2.5 million acre feet), from which water is exported from the Trinity River to the Sacramento River basin to augment water supplies for the Central Valley Project. The Potter Valley Project, in the upper Eel River Basin (Lake County), is a small hydropower project owned and operated by Pacific Gas and Electric (PG&E)[2]. The Project also functions as an inter-basin transfer and exports water from the Eel to the Russian River watershed in Mendocino County. The Humboldt Bay Municipal Water District serves the Humboldt Bay region and relies on Ruth Reservoir

1 For more information on climate change effects on the Sacramento River watershed, we refer to the reader the Sacramento Valley Regional Report of the Fourth Assessment.

2 PG&E initiated Federal Energy Regulatory Commission, or FERC, relicensing process for the Potter Valley Project in 2017 but recently announced they will be putting the Project up for auction in the late 2018.

for water storage, Mad River for conveyance, and a series of collector wells in the lower river to deliver water to municipal water treatment facilities. Other cities, rural communities, and agricultural water users in the region are supplied by small local surface water and groundwater systems.

The North Coast region has been shaped by the collision of tectonic plates that cause land uplift, major earthquakes, and geologic instability (Clarke and Carver 1992). Active tectonics also contribute to a diversity of landforms and vegetation types in the region (Mooney and Zavaleta 2016). Soils of the Coast Range Province are characterized by a Coastal Belt dominated by shales, a Central Belt characterized by a clay-rich mélange, and an Eastern Belt dominated by metasedimentary and metavolcanic rocks. Mixed broadleaf-needleleaf evergreen forests cover the Coastal and Eastern Belts, whereas grassland-deciduous broad-leaved savannah and chaparral cover the Central Belt's mélange. Geology, not precipitation, often controls the boundaries between forest and savannah due to differences in the weathered bedrock that store water that is available to plants. In the Coastal Belt, stored water in the deep weathered bedrock drains groundwater slowly and sustains stream flow into the dry season (Rempe and Dietrich 2014, Salve et al. 2012). In contrast, weathered bedrock in the Central Belt is shallow, and hillslopes quickly shed rather than store water (Hahm et al. 2018). These Central Belt hillslopes saturate during intense rain to generate overland flow, increasing the propensity of streams to flash flood in winter and go dry in the summer. The Klamath Mountain Province east of the Coast Range includes several mountain ranges that rise over 9,000 feet in elevation, including the Siskiyou, Marble, Trinity, and Salmon Mountains. Mount Shasta (14,179 feet) in Siskiyou County is the highest mountain in the region and fifth-highest in the state. Soils in the Klamath Mountain province are dominated by metasedimentary and metavolcanic rocks, but also include belts of ultramafic rock such as serpentine, which have a chemical composition unsuitable for most vegetation and support a unique community of plant life. Extreme topographic relief, including mountain slopes up to 100% grade, coupled with a strong climatic gradient, contributes to a high diversity in vegetation communities and disproportionate representation of plant and animal species found nowhere else in the state (Sawyer 2006).

The abundance of natural resources is a defining feature of the North Coast and has had a strong influence on the region's cultural and economic development. Soon after the arrival of Europeans, the Klamath-Trinity region became a hotspot for placer and hydrologic mining. The north State's Gold Rush of 1850-1900 resulted in displacement of Native Americans and physical alteration of the region's gold-rich riverine corridors. The region's large rivers historically supported abundant populations of migratory fishes, such as salmon and lamprey, which Native American tribes sustainably managed through cultural and technological means (Swezey and Heizer 1977). Salmon rivers in the North Coast region supported a thriving commercial fishery through the mid-20th century, but early mining, forestry, overfishing, and sustained habitat loss has gradually led to the decline of salmon runs and associated coastal fishing industry (Yoshiyama and Moyle 2010).

The degradation of riverine habitats was accelerated by the exploitation of forests, another abundant natural resource in the region. In the mid-19th century, a logging boom commonly known as California's "second Gold Rush" deforested thousands of acres of old-growth redwood forests, leaving only 4-5% of their historical distribution in California (Mooney and Dawson 2016). Logging of redwood, pine, and fir continued at a rapid rate through the 19th and late-20th century, supporting several large mills in the North Coast region. Landslides associated with extreme wet years (1862, 1890, 1955, and 1964), and compounded by logging and roads, delivered massive volumes of sediment and debris into stream channels, leaving rivers wider, shallower, and warmer (Lisle 1990). Some streams show signs of recovery, but many river basins in the region are still listed as impaired for sediment and temperature as a result of legacy logging activities. The logging boom also supported an industrial pulp mills on Humboldt Bay. Since the 1990s, the pulp mills have closed and harvests from both federally and privately-owned timberland have declined owning to new policy, endangered species protections, and other regulatory constraints. Nevertheless, the region remains the top producer of the timber in the state (McIver et al. 2015).

Coastal California Redwoods remain the iconic symbol of the North Coast region. (Photo: Jessica Harrison)

Despite the legacy impacts of mining and intensive logging on the landscape, the North Coast retains some of highest quality habitats for fish, wildlife, and plants in California. The region includes several rivers that are considered critical salmon recovery "strongholds", areas where habitats are still largely intact and help to sustain wild Pacific salmon species (Wild Salmon Center 2010). The region also hosts many rare endemic plants and wildlife species (DellaSala et al. 1999). Much of the region is now protected to some degree under public ownership, including National and State Parks, National Forests, and conservation areas managed by the Bureau of Land Management. Portions of the Eel, Smith, Klamath, and Trinity Rivers have also been designated as Wild and Scenic, providing some protection from future water development.

The cannabis industry is a major contributor to the regional economy and has had a growing impact on the environment. In the 1970s, counterculture migrants developed the region's first cannabis farms, concentrated in Humboldt, Mendocino, and Trinity Counties, or the "Emerald Triangle." These operations evolved into large-scale and socially-pervasive production in the 1980s and 1990s, with rapid growth after medical marijuana was legalized in 1996, and further acceleration as the movement towards legalization advanced in California (Butsic et al. 2017, Polson 2013, 2017). From 2012-2016, it is estimated the cannabis production increased by over 200% in Humboldt County (Van Butsic pers. comm.). Historically, the illegal status of cannabis incentivized production in remote, wildland areas, where steep slopes, critical wildlife habitat, and proximity to streams heighten the risk of environmental damage (Butsic and Brenner 2016). Reductions in streamflow from water diversions, contamination of water, and poisoning of wildlife have all been linked to cannabis production in the region (Carah et al. 2015).

Recent state legalization and new regulatory systems are rapidly changing cannabis production practices, which have unknown but significant implications for the regional economy and environment.

The government, health, and education sectors together provide most of the region's employment (~48%) (California Economic Forecast 2016). Employment in retail, leisure, and hospitality accounts for approximately 25% of the workforce, while manufacturing, construction, and other professional services each support less than 5% of the workforce (California Economic Forecast 2016). Industries such as forestry, fishing, ranching, and agriculture have shrunk substantially over time. Nevertheless, management of natural resources continues to affect the quality of life and economic well-being of the region's inhabitants and is of critical importance to the preservation of indigenous community cultural resources upon which knowledge systems, economies, livelihoods, and traditions rely. Tourism to enjoy the region's natural beauty is a significant and growing contributor to the economy and timber harvesting, fishing, and aquaculture operations remain important. Overall, however, the economy is weaker than other coastal regions of the state. Persistent unemployment, a limited tax base, and high housing costs have contributed to rising homelessness, food insecurity, and overtaxed social welfare programs. Most of the region meets the State's definition of disadvantaged communities, where median household income is less than 80% of the statewide median (DWR 2013b).

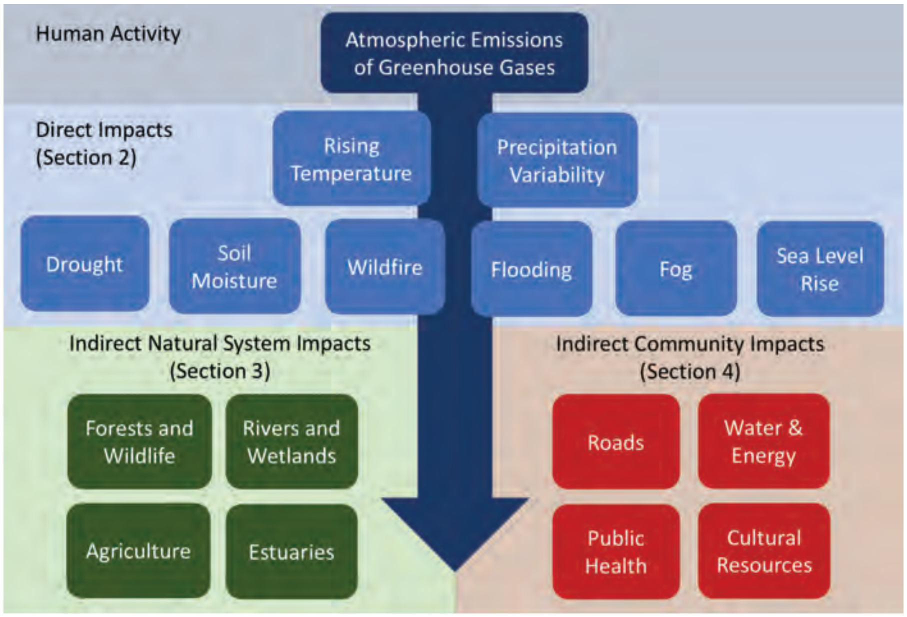
Climate change is one of many factors that will influence how the region's environment, economy, and communities will evolve over the next century. Population growth, new technologies, land use change, and geopolitical events are among others that will also shape the future of the North Coast. However, climate change is rapidly become the dominant force affecting human wellbeing and ecosystems on the planet (Ostberg et al. 2018). In the North Coast region (and throughout much of the state), natural hazards are a persistent and growing risk to both rural and urban communities. Fire, flooding, landslides, and coastal storm surges threaten homes, critical infrastructure, economic activity, and public health. Shifts in seasonal weather patterns are increasing stress on ecosystems, threatening forests, fish, and wildlife. Understanding the regional consequences of climate change and identifying strategies to ameliorate climate risks is critical for the health of people, communities, and the environment.

North Coast Region Climate and Climate Projections

This section explores the direct impacts of global climate change to the North Coast region, including observed historical trends and projected future changes according to global climate models as well as recent scientific literature on the subject. Climate patterns are driven by globally interconnected flows of energy and water in the atmosphere and oceans. Human activities impact climate through land-use change and emissions of greenhouse gases and aerosols. In the North Coast region, changes to the local climate are seen in rising temperatures, changing precipitation patterns, shifts in fog dynamics, sea-level rise, and drought. These direct consequences of climate change have significant indirect impacts on natural resources, public health, and economic assets of local concern (**Figure 2.1** and addressed in later in the report).

Climate scientists have developed global climate models (GCMs) that can be used to simulate future climate as a function of emissions of greenhouse gases (GHGs) from human activities, the concentration of GHGs in our atmosphere, global atmospheric and ocean processes, and changes in temperature. Some scenarios assume that use of fossil fuels and emissions of GHGs will remain constant into the future, while others assume that humans will take action to reduce GHG emissions. Different climate models also make different assumptions about the way global ocean-atmospheric processes will respond to rising GHG concentrations and temperatures. The resulting range of projections, therefore, reflects the uncertainty that comes with predicting future human activities and their influence on the climate. Importantly, climate projections describing long-term atmospheric behavior under a given emissions scenario should not be interpreted as weather predictions (forecasting of short-term atmospheric behavior). Climate projections cannot tell us what will happen on a given date in the future, but can provide useful information about what to expect from our future climate in general. They can tell us long-term trends in precipitation

FIGURE 2.1



Atmospheric emissions of greenhouse gases have direct effects on temperatures, precipitation patterns, the water cycle, fire, and sea levels. These hydro-climatic changes will alter natural system dynamics, including terrestrial and freshwater ecosystems, and agriculture. Climate change will also have significant indirect impacts to transportation networks, water and energy infrastructure, public health, and cultural resources.

and temperature, how much snow we can expect to accumulate in a typical future year, and how often (but not when) extreme events such as heat waves, droughts, and heavy rainfall are likely to occur. For more information on the causes of climate change and effects of carbon dioxide and other greenhouse gases we refer the reader to the Climate Science Special Report of the Fourth National Assessment (U.S. Global Change Research Program 2017).

Most GCMs produce outputs regarding global climate measures (including temperature, precipitation, winds, and other variables) that are rather coarse, typically for 60 to120-mile grid cells. However, regional climate studies typically employ data derived from the global models using a "downscaling" technique to better represent the more detailed variability over an area of interest, so that the results are compatible with regional planning and decision-making. For the Fourth Assessment, selected variables of interest from the coarse-scale global model simulations have been downscaled over California's complex terrain to finer grid cells of approximately 4 miles using a statistical technique called "Localized Constructed Analogs", or LOCA (Pierce et al. 2015). Additionally, because models are mathematical approximations to the physical, chemical, and biological systems they are aiming to simulate, the results from global and regional models are usually somewhat different from those observed in nature. Because of this, temperature, precipitation, and other variables of interest in regional projections have been "bias corrected" so that the model-simulated output is adjusted to match the averages and other statistical properties of observations over the historical period.

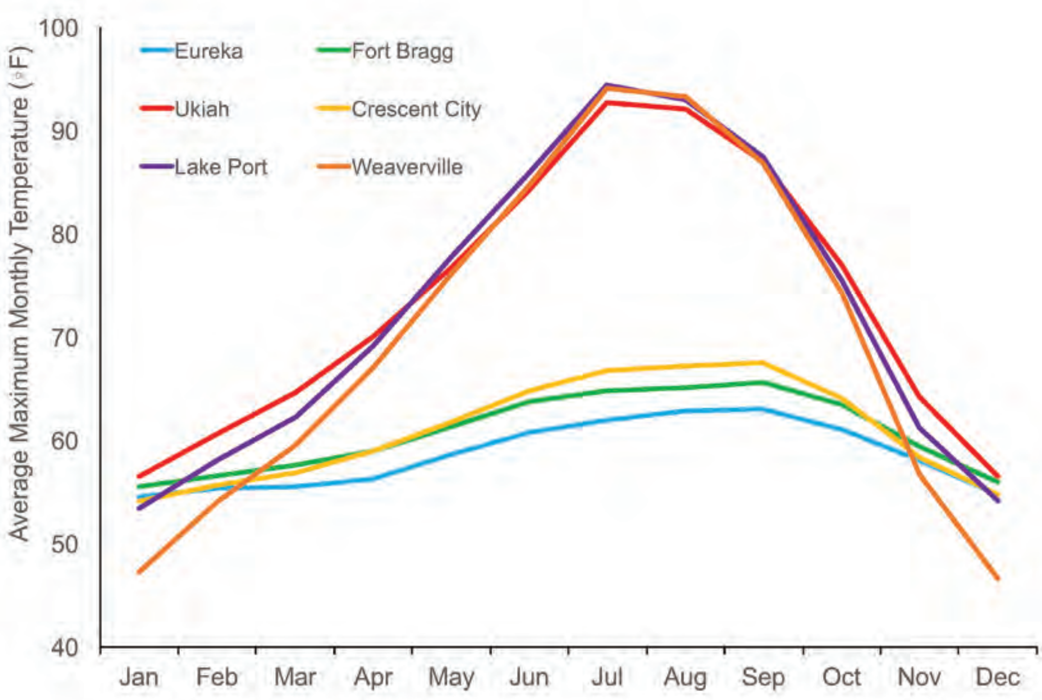
Many alternative GCMs have been developed by research scientists. In California, a group of experts selected ten GCMs as being the most suitable for state climate change studies (DWR 2015). These were selected based on their performance in simulating historical climate conditions and representation of a range of plausible climate futures for California, including "warm/dry", "average", and "cooler/wetter" scenarios. For each model, two emissions scenarios were considered: a "business-as-usual" scenario in which GHG emissions continue to rise over the 21st century (Representative Concentration Pathway [RCP] 8.5) and a moderate emissions scenario (RCP 4.5), in which GHG emissions level off by mid-century and decline to 1990 levels by the end of century. In this section, statements regarding future climate conditions are generally drawn from predictions from the average of ten priority climate models under the business as usual emissions scenario, unless otherwise noted. The underlying climate data, along with mapping and other visualization tools, can be found at cal-adapt.org.

Rising Temperature and Extreme Heat

Temperature is a direct indicator of climate change, and is an important factor affecting agriculture, forestry, and water supplies as well as human and ecosystem health. Evidence of anthropogenic climate warming is already apparent in California, where minimum, average, and maximum temperatures have all been increasing over the past century (CEC/CNRA 2018). Statewide annual temperatures have increased by about 1.5 °F in the last century, heat waves are becoming more common, and snow is melting earlier in the spring. Minimum temperatures – which correspond to night time lows – have been increasing at a faster rate than both maximum daytime highs and average temperatures since the mid-1970s. Furthermore, the magnitude of temperature increases has been greatest in the warm summer months, increasing the frequency of extreme heat events that threaten human health, stress water and electric utility systems, and impact terrestrial and freshwater ecosystems.

In the North Coast region, increases in annually averaged mean daily temperature has been limited to under 1 °F over the last century and annually averaged maximum temperatures for the region have ranged between 60 and 64 °F. However, there is substantial differences in temperature across the region. Coastal cities such as Eureka, Crescent City, and Fort Bragg have annually averaged maximum temperatures around 60 °F, with average maximum summer temperatures below 70 °F (**Figure 2.2**). In contrast, cities in the interior zone of the region, including Weaverville, Ukiah, and Lake Port, experience annually averaged maximum temperatures greater than 70 °F and average monthly maximum temperatures over 90 °F (**Figure 2.2**)

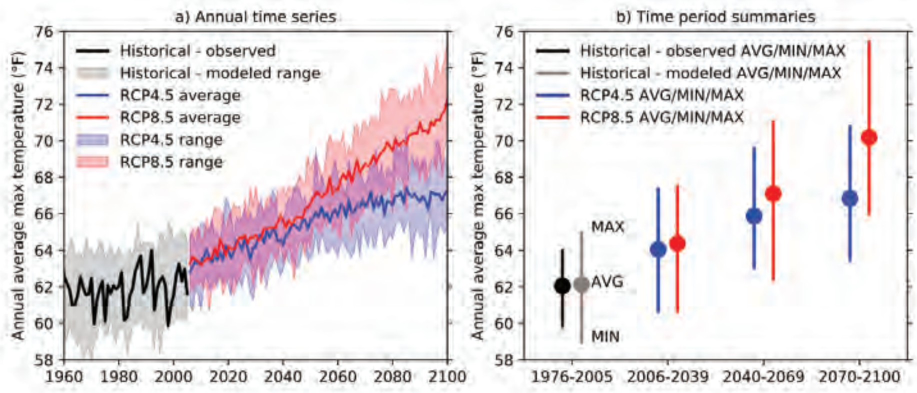
FIGURE 2.2



Observed long-term maximum temperatures for select cities in the North Coast Region (Source: weather stations with at least 80 years of record from the Western Regional Climate Center).

Region-wide, average annual maximum temperatures are projected to increase by 5 to 9 °F by end-century under moderate and high emission scenarios (**Figure 2.3**), respectively, with the greatest temperature increases projected for the interior zones of the region, especially in Siskiyou County and parts of Trinity County (**Figure 2.4, Table 2.1**). Projected changes in temperature show similar spatial patterns for the hottest day of the year (**Figure 2.5**), with most of the region outside of the coastal zone exceeding 105 °F. Using a similar suite of climate projections as those selected for the Fourth Assessment, Micheli et al. (2018) estimated that summer season temperatures in the North Coast region will increase 3-5 °F by mid-century (2040-2069) and 6-9 °F by end-century (2070-2099). Winter season temperatures are expected to increase by a greater magnitude: 5-7 °F by mid-century and 8-11 °F by end-century.

FIGURE 2.3



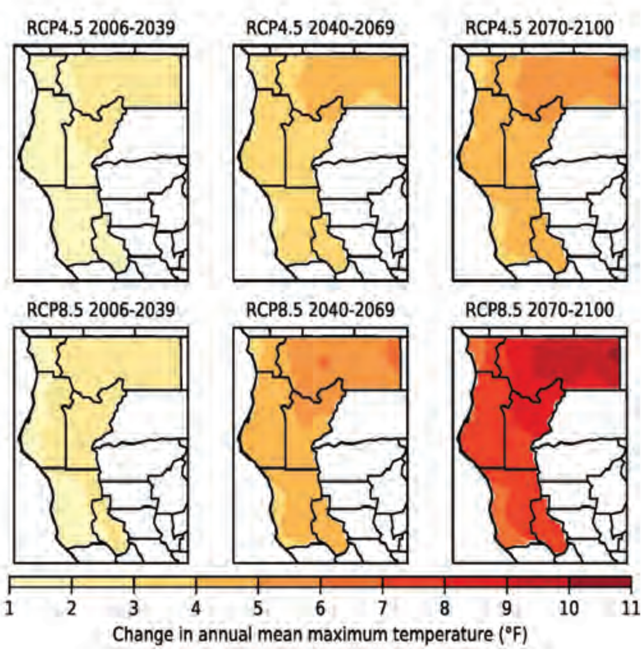
Historical observed (black) and historical modeled (gray) annually averaged maximum daily temperatures (°F) for the North Coast region, displayed as (a) annual time series and (b) time period summaries. Future, projected changes in maximum daily temperatures are displayed for moderate (RCP 4.5 – blue) and business-as-usual (RCP 8.5 – red) emissions scenarios (Source: LOCA-downscaled maximum temperature data from ten priority global climate models).

TABLE 2.1

	HISTORICAL (1950-2005)	EARLY CENTURY (2020-2039)	MID-CENTURY (2040-2069)	END CENTURY (2070-2099)
Mendocino	65.4	68.1	69.9	72.8
Humboldt	60.4	63.2	65.1	68.2
Del Norte	57.4	60.0	61.8	64.8
Lake	68.0	70.9	72.9	75.8
Trinity	61.5	64.7	66.7	69.9
Siskiyou	60.0	63.5	65.9	69.4

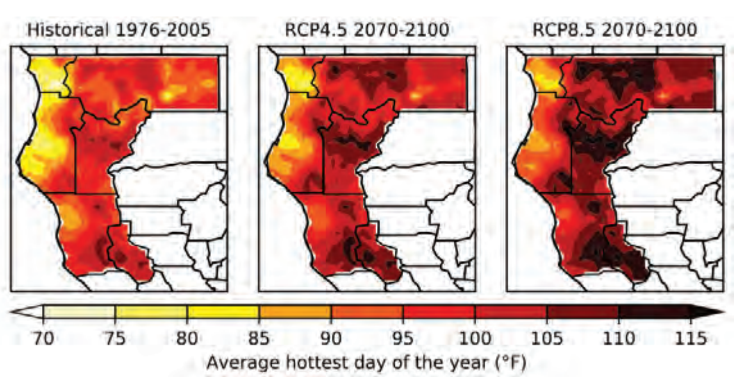
Historical and future modeled annually averaged maximum daily temperatures (°F) for North Coast region counties under a business-as-usual (RCP 8.5) emissions scenario (Source: regional LOCA-downscaled data from ten priority global climate models).

FIGURE 2.4



Projected changes in annually averaged maximum temperatures under moderate (RCP 4.5) and business-as-usual (RCP 8.5) emissions scenarios for early, mid, and end of 21st century (Source: LOCA-downscaled data from ten priority global climate models).

FIGURE 2.5



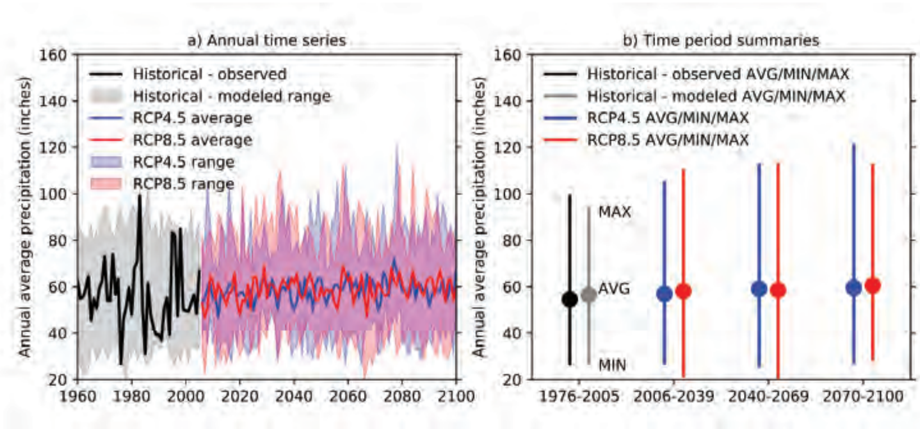
Average projected temperature of the hottest day of the year for business-as-usual (RCP 8.5) emissions scenarios for early, mid, and end of 21st century (Source: LOCA-downscaled data from ten priority global climate models).

Increasing Precipitation Variability

With its characteristic Mediterranean-type climate, California is known for its high seasonal and year-to-year precipitation variability. In the North Coast, most annual precipitation falls in the winter between November and March, typically delivered in a few large storms. The most intense storms are often associated with "atmospheric rivers" that are fed by long streams of water vapor transported from the Pacific Ocean and can carry more water than 7 to 15 Mississippi Rivers combined (Ralph and Dettinger 2011). These storms result in heavy rainfall over a narrow area. They contribute an average of 40% of the annual snowpack in California (Guan et al. 2013) and the presence or absence of these large storms have a major effect on water supplies in any given year (Dettinger et al. 2011). However, they also present substantial flood risk, especially for the Russian River (Ralph et al. 2006).

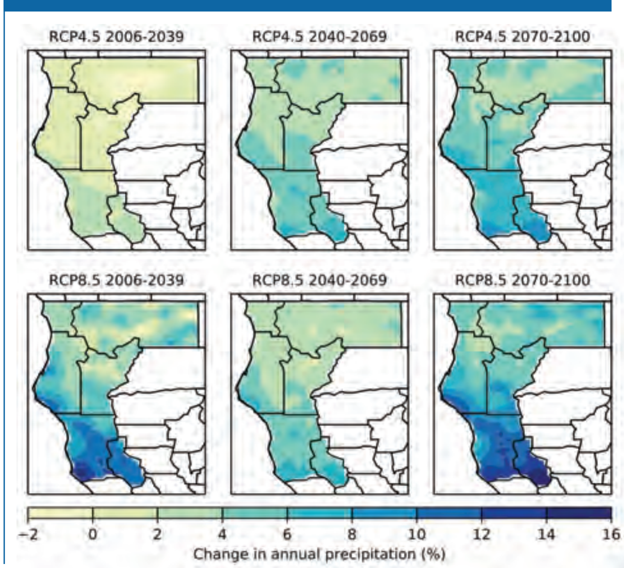
At a statewide level, future trends in precipitation are uncertain, with some models suggesting modest increases in annual precipitation while others suggest lower precipitation relative to recent historical conditions (Neelin et al. 2013). In the North Coast region, model predictions of annual precipitation fall within the range of historical variation (**Figure 2.6**), but trend towards slightly higher (2-16%) precipitation across the region by the end of century (**Figure 2.7**). Despite

FIGURE 2.6



Historical observed (black) and historical modeled (gray) changes in average annual precipitation (inches) for the North Coast region, displayed as (a) annual time series and (b) time period summaries. Future, projected changes in annual precipitation are displayed for moderate (RCP 4.5 – blue) and business-as-usual (RCP 8.5 – red) emissions scenarios (Source: LOCA-downscaled maximum temperature data from ten priority global climate models).

FIGURE 2.7

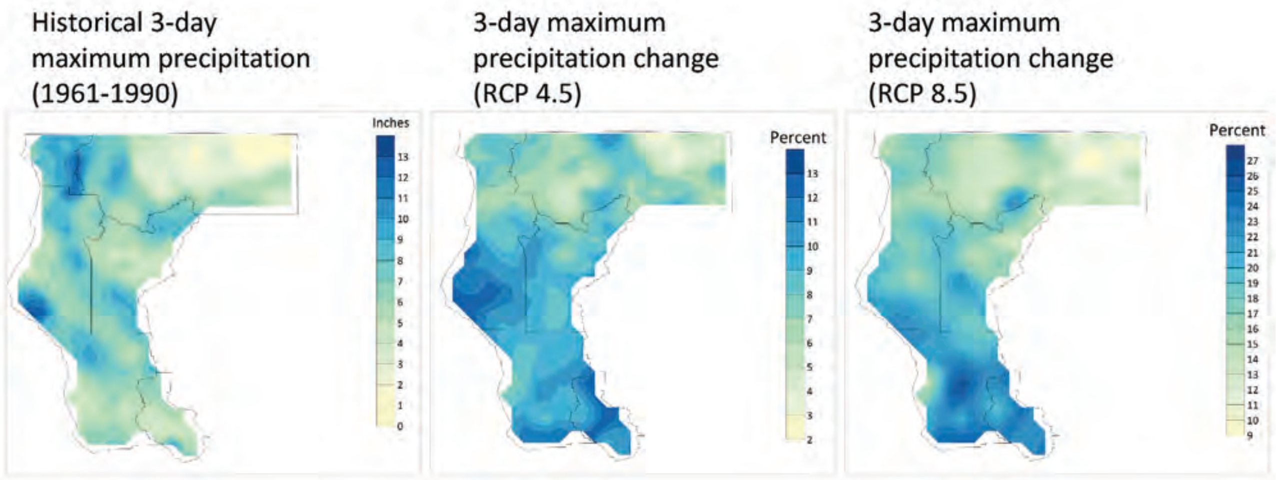


Projected changes in average annual precipitation under moderate (RCP 4.5) and business-as-usual (RCP 8.5) emissions scenarios for early, mid, and end of 21st century (Source: LOCA-downscaled data from ten priority global climate models).

potentially small changes in annual precipitation, recent research indicates that the precipitation variability is likely to increase in the future (Swain et al. 2018).

The North Coast region already experiences the most intense storms in the state in terms of three-day maximum precipitation. Climate change projections indicate that the intensity of individual storms will increase in the future (Pall et al. 2017, Prein et al. 2017, Risser and Wehner 2017) (**Figure 2.8**). Swain et al. (2018) conducted a climate modeling study that concluded that California will experience a 100-200% increase in the occurrence of very high seasonal precipitation (similar to 2016-2017 water year) by the end of the 21st century. According to Swain et al. (2018), the frequency of a 200-year recurrence interval flood, similar to the flood of 1862 which inundated Los Angeles and a 300-mile swath of the Central Valley, increases by 300-400%. AghaKouchak et al. (2018) also predict a rise in extreme precipitation, with historical floods of one-in-a-hundred-year magnitude (1% chance of occurrence per year) occurring in the future with a 2.5% chance per year in San Francisco and a 4% chance per year in Sacramento for 2050-2099. Cities further north were not analyzed in the study.

FIGURE 2.8



Historical 3-day average maximum precipitation and projected changes in 3-day maximum precipitation for end of century (2070-2099) under moderate (RCP 4.5) and business-as-usual (RCP 8.5) emissions scenarios (Source: Cayan et al. 2018).

Swain et al. (2018) also report that seasonality of California's wet season will be compressed in a shorter period of time, resulting in later onset of the rains in the fall and earlier spring drying. Paradoxically, the projected rise in the frequency of precipitation extremes is coupled with an expected rise in the frequency of extremely dry years, on the order of 80% across most of northern California (Swain et al. 2018). The coupled rise in the frequency wet and dry year extremes has been termed "precipitation whiplash" and describes a new climate regime for the state characterized frequent, dramatic swings between wet and dry years.

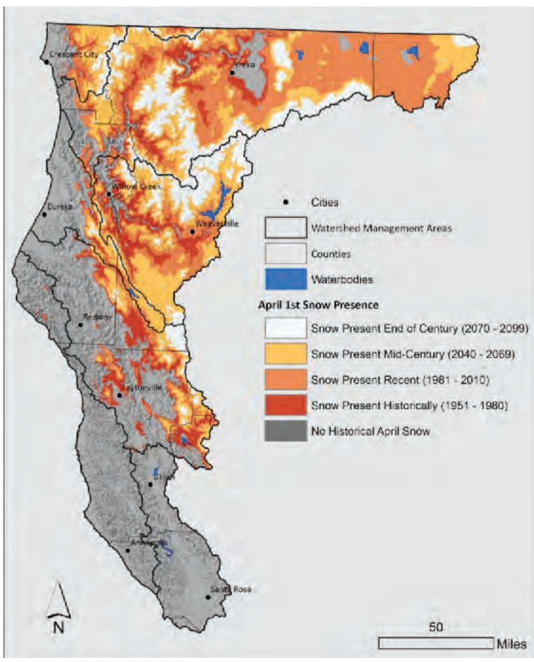
Drought

Drought is a common, recurring feature in California (Griffin and Anchukaitis 2014). The 2012-2016 California drought led to the most severe moisture deficits in the last 1,200 years (Griffin and Anchukaitis 2014) and a 1-in-500 year low in Sierra Nevada snowpack (Belmecheri et al. 2016). The development of a persistent, high pressure system in the north Pacific, coined the "ridiculously resilient ridge" by climate scientist Daniel Swain, is considered to be the primary cause of precipitation deficits during the statewide drought (Seager et al. 2015, Swain 2015). Researchers cite the ridge for steering storms northward, away from California, and suggest that the persistence of the ridge was possibly reinforced by melting of artic sea ice (Cvijanovic et al. 2017) and sea surface temperature anomalies (Wehner et al. 2017). Despite the record-breaking nature of the 2012-2016 drought, paleoclimatic records have shown that even longer periods of drought, i.e., mega-droughts that span decades to centuries, have occurred in California's past (Cook et al. 2006, Malamud-Roam et al. 2007). In recent years, the influence of anthropogenic climate change on drought occurrence and persistence has been a major topic of interest (Angélil et al. 2017, Cheng et al. 2016, Diffenbaugh et al. 2015, Mann and Gleick 2015, Seager et al. 2015, Swain 2015). Most of the studies have concluded that current and future increases in temperature, regardless of changes in precipitation, raise the probability of enhanced drought magnitude and duration in California (Diffenbaugh et al. 2015, Wehner et al. 2017). This has major implications for municipal and rural water supplies, agriculture, human health, and the environment.

Loss of Snowpack

California's snowpack is universally projected to decline in response to regional warming, even for climate scenarios that suggest precipitation increases. Micheli et al. (2018) analyzed historical and potential future snow conditions in an area that largely overlaps the North Coast region. Using a coupled climate and land-surface model (Flint et al. 2013), they analyzed snow cover and "snow water equivalent", a proxy for snow depth, for historical and projected future periods. They report that the average spatial extent of snow on April 1st has declined from 60% to 50% within areas exceeding 3,000 feet in elevation between 1951-1980 and 1981-2010, with the greatest loss of snow occurring in the Klamath-Siskiyou Mountains. Under a warm, moderate rainfall climate scenario, they predict that the April 1 extent of snow will decline to 11% by end-of-century (**Figure 2.9**) and April 1 snow water equivalent will decline from 10.3 inches (1951-1980) on average to 1 inch by end century. Snow losses are greatest for warm, low-rainfall climate scenarios.

FIGURE 2.9

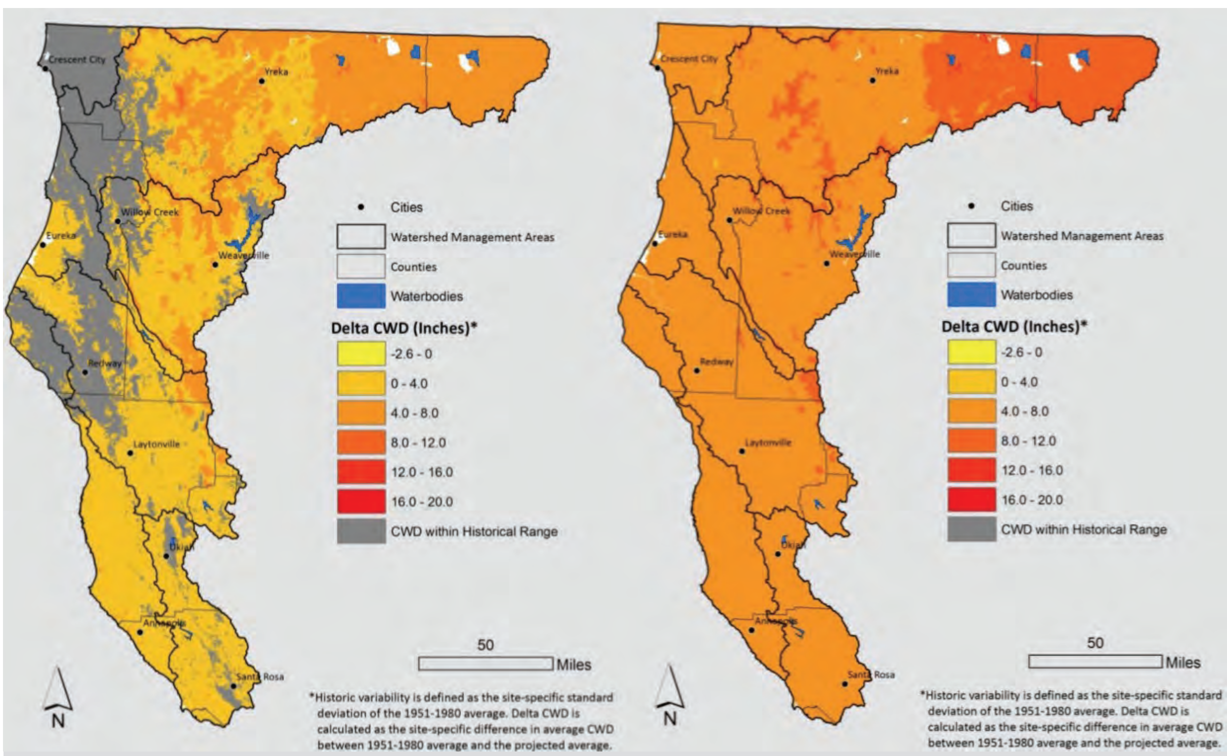


Historical and projected footprint of April 1 snow cover (Source: Micheli et al. 2018).

Soil Aridity

For the North Coast region, an increase in inter-annual rainfall variability, a compressed wet season, loss of snowpack, and higher temperatures will collectively increase climatic water deficits, which relates to the amount of water in the soil available to plants. An increase in the frequency and/or magnitude of climatic water deficits translates to increasing stress experienced by vegetation on the landscape. Micheli et al. (2018) estimate that climatic water deficits in the North Coast region may increase by 10-19% by mid-century and 16-32% end-century. The end-century changes correspond to an effective loss of 3-6 inches of annual rainfall. Even under wetter climate projection scenarios, increasing temperatures are expected to result in greater climatic water deficits relative to historic conditions for most of the North Coast (**Figure 2.10**). In fact, nearly all of the North Coast region is projected to experience water deficit conditions (drought stress on soils) exceeding a standard measures historical variability (1 standard deviation) by end-century (Micheli et al. 2018).

FIGURE 2.10



Increases in climate water deficits (CWD) exceeding natural historical variability by end of century for a warm, moderate rainfall climate scenario (left panel) and a hot, dry climate scenario (right panel) (Source: Micheli et al. 2018).

Wildfire

The fire ecology of the North Coast is as diverse as its climates and vegetation. The region includes a wide range of ecosystem types, which collectively span a spectrum of infrequent- to frequent-fire and low- to high-severity fire regimes. Thus, interactions with climate in the region are variable, and changing climate regimes will have differential influences across the North Coast. However, there is general agreement that temperature increases will extend fire season throughout the region, and especially in higher elevation sites with variable and decreasing snow pack (Micheli et al. 2018, Westerling et al. 2006). Lightning ignitions have historically been the most common cause of fire in the region, and lightning-ignited wildfires are likely to increase due to a longer fire season and more available fuels (data from other parts of CA support this assumption; see Lutz et al. (2009)). Increased populations will also increase the probability of human-ignited wildfire, especially in more populated parts of the North Coast (Krawchuk and Moritz 2012, Micheli et al. 2018). A changing climate combined with anthropogenic factors has already contributed to more frequent and severe forest wildfires in the western U.S. as a whole (Westerling 2016, Mann et al. 2016, Abatzoglou and Williams 2016). Westerling et al. (2011) predict that increases in area burned in northern California forests will exceed 100% in both lower and higher emissions scenarios. Increased fire frequencies and fire severities will favor more frequent-fire adapted and/or early seral vegetation communities, including oak woodlands and chaparral (Ackerly et al. 2015).

Streamflow and Flooding

Summer streamflow has declined in northern California and southern Oregon over the last half-century, according to a study by Asarian and Walker (2016). They found the most consistent declines in monthly streamflow for August through November, with 73% of sites showing a declining trend in September streamflow. Among 41 flow monitoring sites evaluated along the coast, approximately half showed significant declines in the magnitude of 7-day, 30-day and 90-day minimum flows. Changes in precipitation alone are not likely the cause of the observed declines as they were evident even in precipitation-adjusted data (Asarian and Walker 2016). Similar findings of dry season flow declines have been reported by Sawaske and Freyberg (2014) for coastal streams across the Pacific Northwest. This study examined annual minimum flows and found that 44% of 54 coastal streams had statistically significant trends in declining annual low-flows. Eleven (of nineteen) sites in northern California showed significant declines in summer low flow. The primary driver for these changes is thought to be increasing summer evapotranspiration as a result of climate change. Increasing tree density, associated with the recovery of forests since the last major logging era, may also be contributing to higher evapotranspiration.

Climate model projections suggest trends of reduced dry season stream flows will continue. For example, Grantham et al. (2018) used statistical models to estimate changes in monthly streamflow by mid-century with the ensemble of climate change model projections recommended for the 4th Climate Assessment (DWR 2015). They report that streamflow is projected to increase in the wet season and decrease in the dry season. January is predicted to experience the greatest increase in flows (model-ensemble median = +25%), while May flows are predicted to have the greatest declines (median = -24%). From June – September and November, the range of predicted flow change bounds the historical average, with some climate models corresponding to increasing and others to declining flow. Naz et al. (2016) used a land surface model to estimate changes in seasonal watershed runoff under a similar ensemble of climate models for the entire U.S. They also report evidence of declining summer and fall runoff for watersheds in the North Coast region.

The predicted rise in the frequency and intensity of drought is likely to further reduce streamflows. For example, Cayan et al. (2018) predict a higher frequency of extreme dry years in California, with severe droughts that now occur once in 20 years, occurring once every 10 years by the end of the century, and once-in-a-century droughts, occurring once every 20 years. As a result, the lowest streamflow occurring each decade is expected to be 30-40% lower by end of century, relative to average historical conditions (1950-2005).

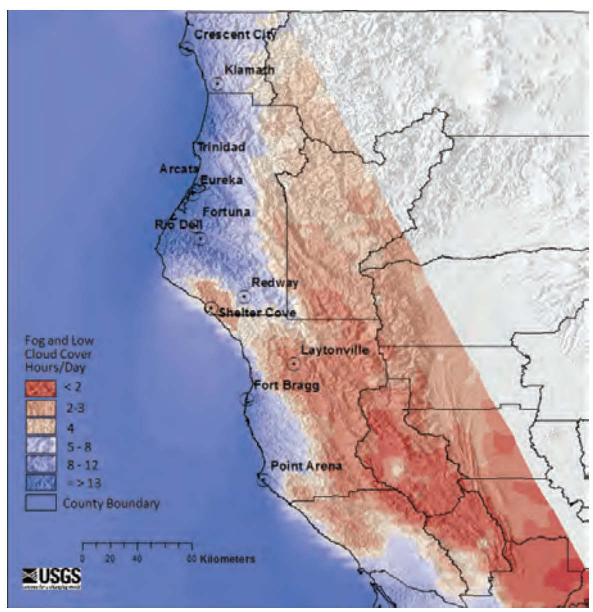
To our knowledge, an analysis of historical flood trends has not been performed for the North Coast region. However, climate model predictions suggest that more precipitation will occur in wet years, increasing flows during the peak streamflow season in winter (Burke and Ficklin 2017, Naz et al. 2016, Grantham et al. 2018). A study by Swain et al. (2018) also suggests that the frequency and intensity of extreme precipitation events will increase, likely intensifying flooding in the North Coast region. High rainfall intensities also increase the likelihood of landslides and debris flows. Water, electricity, and transportation infrastructure designed for a milder climate will be at risk with larger and more frequent storms and flood events.

Fog Dynamics

Fog is a defining feature of California's coastal zone and is found year-round in the North Coast. Coastal fog is produced when an upper atmosphere layer of dry warm air settles on top of a moist layer of air, trapping it next to the cold ocean in an inversion. As the moist layer loses heat to the ocean, the water vapor in the air condenses into fog droplets. Coastal fog is affected by ocean currents and upwelling, as well as the strength of the inversion layer. The type of aerosols on which the vapor condenses can also change the dynamics of fog formation by influencing fog droplet size. Aerosols can be a mixture of salts and organic molecules evaporated from sea spray, pollution, long distance dust transport, and microorganisms. The complexity of the interacting processes make it difficult to accurately forecast the occurrence of coastal fog (Koračin et al. 2014).

The spatial pattern of fog and low cloud cover on the North Coast is relatively consistent and is affected by the shape of the coastline relative to prevailing winds, elevation, and orientation of terrain features (Renault et al. 2016, Torregrosa et al. 2016). The north sides of capes and low-lying valleys exposed to northwest winds are associated with the highest occurrence of summertime fog (**Figure 2.11**). Along the coast, areas sheltered from northwest winds by coastal mountains or in the lee of capes experience the least fog. Decadal frequencies of fog range from a summertime average of less than 2 hours of fog per day in Shelter Cove to more than 14 hours per day in low-lying areas near Eureka.

FIGURE 2.11



Average fog cover in hours per day in the North Coast region (1999-2009). The data were derived from over 26,000 hourly satellite images from the National Weather Service.

Summertime fog plays a vital role in coastal ecosystems. Coastal forests get up to a third of their water from fog (Burgess and Dawson 2004) and many fog-dependent plants, such as redwoods, are able to take in water directly through their leaves (Dawson 1998). Fog drip can be lifesaving to plants in the forest understory and to aquatic organisms, such as salmon, in streams that would otherwise dry out during the dry season. Shade from summertime fog cools coastal systems (Walker and Anderson 2016) and reduces the rate of plant evapotranspiration (Chung et al. 2017), causing plants to use less subsurface water reserves (Burgess and Dawson 2004) and leaving more water in the system (Flint et al. 2013). In the high-fog areas of Santa Cruz Mountains, researchers found summer streamflow increased by 100% during fog events and, after a 2-day lag, up to 200% (Sawaske and Freyberg 2015). The disappearance of fog in late summer can exacerbate climatic water deficit for entire watersheds, increasing fire risk. In urban areas, the disappearance of summertime fog leads to warmer summertime temperatures that result in greater electrical demand for cooling and heat stress human health risks.

Reductions in summertime coastal fog have been reported from many regions in the world, including Hokkaido, Japan (Sugimoto et al. 2013); Kiril Islands, Russia (Zhang et al. 2015), and Europe (Egli et al. 2017). However, coastal fog trends on the North Coast are not conclusive. Researchers analyzed fog records from Arcata and Monterey airports and did not detect a significant change in fog occurrence over the last 60 years, but by using statistical methods to reconstruct historical records, they found that the frequency of fog had decreased by 33% since the beginning of the 20th century (Johnstone and Dawson 2010). Another study that relied on physical simulation models suggested long-term 12- 20% reduction in coastal fog for California over the 1900-2070 period (O'Brien et al. 2012).

Future summertime fog trends for the North Coast are difficult to project because fog is affected by several ocean-atmospheric processes that interact in ways that are still not fully understood. For example, increasing temperatures in California, a projection common to all global climate models, can act to increase the coastal to inland temperature gradient which is commonly suggested as causing inland incursion of coastal fog. However, recent satellite-based analyses show that days with high inland temperatures, strong updrafts, and sea breeze type circulation are less likely to have coastal low clouds. The same atmospheric conditions that are conducive to the formation and subsequent onshore transport of marine low clouds are also associated with higher inland summer temperature. Coastal cloudiness and high inland temperatures have an associative rather than causal connection (Clemesha et al. 2017a). Higher inland temperatures lead to stronger onshore sea breezes and are projected to increase in the future (Wang Meina and Ullrich 2018). Increased winds projected globally under climate change (Sydeman et al. 2014) could increase upwelling and, consequently, condensation due to colder sea surface temperatures (SST). This is bolstered by the correlation found by Dorman et al. (2017) of minimum SST co-occurring with maximum fog off the coast near Eureka. However, not all cold SST conditions produce fog. Upwelling and fog data collected near Bodega Bay Marine Laboratory show a weak relationship (Paes et al. 2012), reinforcing studies that conclude atmospheric dynamics are more influential to coastal fog than upwelling (Clemesha et al. 2017b, Leipper 1994).

More research is needed to understand how fog dynamics on the North Coast will be affected by climate change. The strongest driver on fog may be the shifts in global circulation patterns that influence the position and speed of the jet stream and cause extreme conditions such as the persistent, high pressure ridge of August 2017 and that are expected to increase in frequency (Francis et al. 2017). Yet global and regional climate models are still lacking in their ability to accurately simulate the meteorological patterns that influence fog. Ongoing work to understand the relationship between fog, species, and ecosystem resilience (Burns 2017, McLaughlin et al. 2017, Torregrosa et al. 2014) and development of models to predict climate change impacts on fog (McCoy et al. 2017, Wang Meina and Ullrich 2018) should improve our skill in fog forecasting in California (Koračin 2017). A major challenge will be to synthesize approaches from traditionally separate scientific domains to develop a more integrated understanding of coastal fog systems that affect ecosystems and people in the North Coast and millions of other coastal dwellers worldwide.

Sea Level Rise

Global sea-level rise is the most well-documented manifestation of climate change. As the global climate continues to warm, ocean water will warm and expand, and continental glaciers and the ice sheets of Greenland and Antarctica will continue to melt. These ice sheets sequester most of the Earth's terrestrial water that is available to elevate sea level. Sea-level rise has been recorded over most of the California coast south of Cape Mendocino at four to eight inches over the 20th Century (Griggs et al. 2017). As the Earth gradually warms, sea-level rise will continue to threaten coastal communities and infrastructure through more frequent flooding followed by permanent inundation of low-lying areas and increased erosion of cliffs, bluffs, dunes, and beaches (Vitousek et al. 2017).

Greenhouse gases from anthropogenic sources that have already been emitted will lead to a sea level in 2050 that is at least 12 inches higher on average compared to a 1991-2009 baseline (Griggs et al. 2017). Different model projections of sea-level rise between now and 2050 are in general agreement on this value. Beyond 2050, however, there are significant differences in sea-level rise projections that are increasingly dependent on the trajectory of global greenhouse gas emissions, and therefore the extent of additional warming. The science of sea-level rise is evolving rapidly, but current models indicate that significantly reducing our carbon dioxide emissions could limit additional sea-level rise to about 2.4 to 4.5 feet by 2100 (Cayan et al. 2018). Failure to meet those goals, however, could lead to rapid ice sheet loss in Antarctica and potential extreme sea-level rise of as much as eight feet by 2100. This is equivalent to a sea-level rise rate about 30-40 times faster than the rate we have experienced over the last century. Additional information on climate change impacts to California's coasts and oceans is provided in a topical report of the Fourth Climate Assessment (Phillips et al. 2018).

Projections of sea-level rise in the North Coast region are complicated by different rates of vertical land motion. Land subsidence along the Pacific Northwest coast drives sea-level rise in some places to rates of 0.09 inches per year, 34 percent greater than the global average rate of 0.06 per year. Furthermore, in the North Coast region, large interseismic tectonic motions along the southern Cascadia subduction zone create distinct and opposing sea-level trends observed between Humboldt Bay and Crescent City. Probabilistic sea-level rise projections for the Humboldt Bay region have been developed based on the work of Kopp et al. (2014) and the local estimates of vertical land motion by Patton et al. (2017). These updated probabilistic projections provide decision makers the most up-to-date and locally relevant information to support planning and

TABLE 2.2

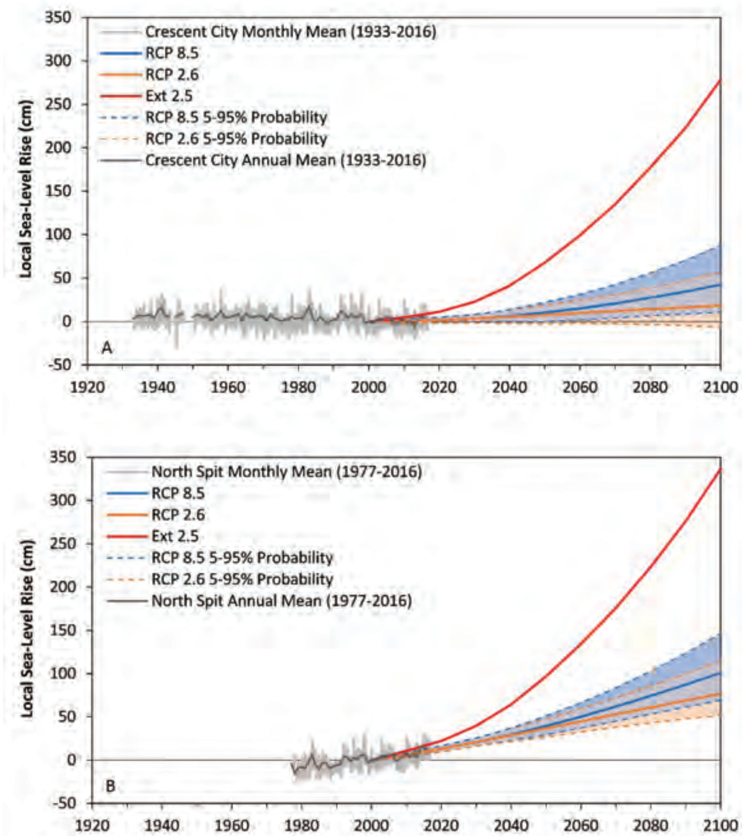
YEAR	SAN FRANCISCO	HUMBOLDT BAY	CRESCENT CITY
2030	0.4	0.6	0.1
2050	0.9	1.3	0.4
2100 (RCP 4.5)	1.9	2.8	1
2100 (RCP 8.5)	2.5	3.3	1.5
2150 (RCP 4.5)	3	4.3	1.6
2150 (RCP 8.5)	4.1	5.3	2.6

Projected median (50% probability) sea-level rise for San Francisco, the north spit of Humboldt Bay, and Crescent City, relative to 1991-2009 mean sea level, in feet (Source: Anderson 2018).

developing adaptation strategies for sea-level rise in the Humboldt Bay region (**Table 2.2**).

Most of coastal California is experiencing interseismic uplift, which ameliorates the effect of sea-level rise. Crescent City, for example, is uplifting faster than long-term global sea-level rise, which results in a negative or decreasing local sea-level rise rate (Anderson 2018) (**Figure 2.12**). In contrast, recent estimates of sea-level rise by Patton et al. (2017) indicate that Humboldt Bay (70 miles to the south) has the highest local sea-level rise rate (0.20 in/yr) in California, greater than both global and regional sea-level rise rates, due to land subsidence in and around the bay. This suggests that global sea-level rise will impact the Humboldt Bay area faster than other parts of the U.S. west coast (Anderson 2018). Further, the findings suggest that accurate measurement of the rate of tectonic land level change will be critical to understanding the impacts of global sea-level rise to the Humboldt Bay region.

FIGURE 2.12



Local sea level projections at Crescent City (A) and Humboldt Bay "North Spit" (B) for high-emissions (RCP 8.5) and low-emissions (RCP 2.6) scenarios, based on data from Kopp et al. (2014), and an extreme (Ext 2.5) sea-level rise scenario from Sweet et al. (2017). The 5th and 95th percentile probabilities are the shaded areas bounded by dashed lines (Source: Anderson 2018).

The impacts of SLR on beaches, communities, and coastal resources will be influenced by the interactions of tides, wave height and energy, and storm surges that produce coastal flooding. Increases in wave heights over the last several decades have been documented along portions of the US West Coast, including the North Coast (Allan and Komar 2006, Menéndez et al. 2008), but these trends have been more recently found to be largely insignificant when adjusted for buoy hardware modifications (Gemmrich et al. 2011). The use of global climate models to determine the future wave climate show a projected poleward migration of storm tracks and generally a slight decrease in wave heights for California overall compared to the historical record (Erikson et al. 2015, Graham et al. 2013).

Periodic El Niño events exert a dominant control on coastal hazards across the region, driven by seasonally-elevated water levels as high as 1 foot above normal, on and 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 major flood damages throughout the state. The pattern, frequency and magnitude of future El Niño events, combined with sea-level rise will be a key driver of coastal flood vulnerability in the coming decades. One study suggested a potential doubling in the frequency extreme El Niños events (Cai et al. 2014), but research to date on future El Niño patterns in largely inconclusive (Collins et al. 2010).

Climate Change Vulnerabilities for Ecosystems and Working Lands

This section examines the consequences of climate change for wild and managed natural landscapes that cover nearly all (98%) of the study region. We focus on impacts to terrestrial ecosystems, including plants and forests as well as wildlife, freshwater ecosystems – including rivers, streams, and wetlands – and agricultural systems.

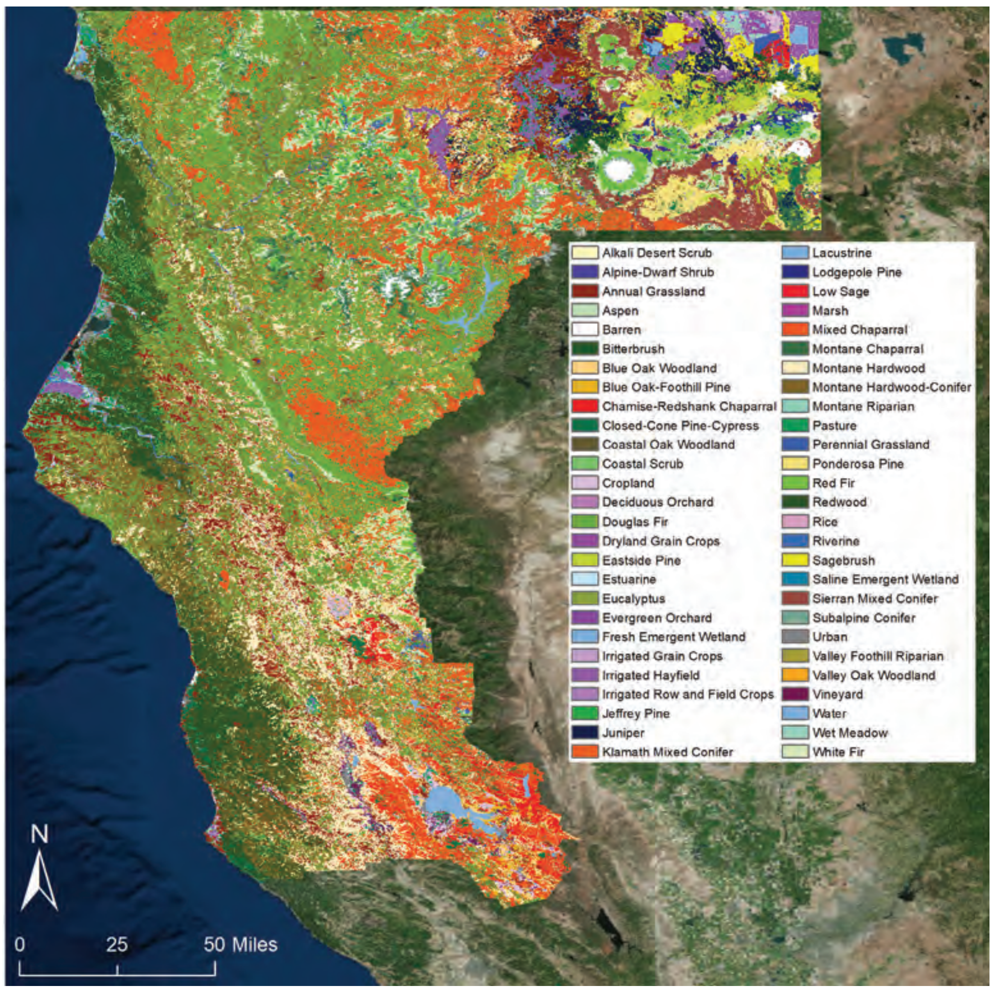
Klamath River in Siskiyou County (Photo: Tony Webster)

Terrestrial Ecosystems

PLANTS AND FORESTS

The North Coast region is geographically and botanically diverse. The region includes low lying coastal redwood (*Sequoia sempervirens*) and Sitka spruce (*Picea sitchensis*) forests in the wet, coastal zones, hardwood forests and shrub vegetation communities in the warm interior regions, and high elevation subalpine forests of the Klamath-Siskiyou Mountains (**Figure 3.1**). Among the region's many unique forest communities, the forests that occupy the higher elevation locations of the Klamath Mountains likely face the greatest threat from climate change in the North Coast region (Devine et al. 2012).

FIGURE 3.1



Vegetation types and land cover in the North Coast region (Source: CALFIRE-FRAP 2015).

The forests along the western boundary of the study area are occupied by a range of species dependent upon summer fog for moisture during the long dry summer. Coast redwood is highly dependent upon fog and the current distribution of redwood is highly correlated to areas that receive fog. Potential changes in fog dynamics (see "Fog Dynamics" section, above), particularly if fog penetration into interior river valleys declines, could have significant impacts on coastal forests. Predicted climate change is expected to cause increased fire frequency and longer fire seasons (see "Wildfire" section, above). The potential outcome of these changes will likely reduce tree densities and depending on fire severity, may result in more landscapes transitioning to early seral conditions. Of the coastal forest species, grand fir (*Abies grandis*) and Sitka spruce are likely more susceptible to climate change than redwood because they have low fire tolerance, whereas coast redwood is highly adapted to fire.

Mixed evergreen and montane conifer forests occupy approximately 40% of the land base in this study area. Common species include Douglas-fir (*Pseudotsuga menziesii)*, tanoak (*Notholithocarpus densiflorus)*, California bay laurel (*Umbellularia californica)*, and Pacific madrone (*Arbutus menziesii)*. These species generally have a moderate resiliency to climate change and are presently adapted to a broad range of temperature and latitudinal gradients throughout this study area. These mixed coniferous (or trees that keep their leaves year-round) hardwoods are capable of sprouting from burls and have adventitious buds that are stimulated by fire or other damaging agents. This type of adaptation helps these hardwood species persist over the long term and following fire. Mature Douglas-fir trees are also moderately adapted to fire by their thick insolating bark, whereas Douglas-fir seedlings are highly vulnerable to fire. Areas to the eastern portion of the study area are where the largest climate water deficit is predicted to occur (**Figure 2.10, pg. 23**) and where the greatest vulnerability is likely to occur with these widely-distributed tree species.

Oaks are common throughout California and about one third of the study area is occupied by oak woodland habitat types. Deciduous (or trees than annually drop their leaves) and evergreen oaks also are sprouting species, have deep tap roots, persist on more marginal soils, and can tolerate broad precipitation and temperature regimes. These qualities help oaks become better adapted to changes in precipitation and longer dry summers. Deciduous oak woodlands, especially Oregon white oak (*Quercus garryana)* and California black oak (*Quercus kelloggii)*, have experienced significant declines over the last 100 years from encroachment by conifers which has been exacerbated by fire suppression (Schriver 2015). This encroachment has been most pronounced during wetter periods of the last 100 years. If the climate change over the next century results in a higher climate water deficit as predicted, oaks in this study region may have greater opportunities and success because of their adaptation to hotter, drier conditions.

The Klamath Mountains escaped extensive glaciation during recent glacial periods, providing both a refuge for numerous taxa and long periods of stability for species to adapt to specialized conditions. Shifts in climate over time have helped make this region a transition zone for plants from the Great Basin, the Oregon Coast Range, the Cascades Range, the Sierra Nevada, the California Central Valley, and Coastal Province of Northern California. This has resulted in a temperate region that is one of the most botanically diverse in the world. The Klamath is recognized for unprecedented coniferous biodiversity with 35 conifer species within the region though many only persist as isolated populations. The rare montane and subalpine conifers within this region are the most susceptible to changes in climate because their populations are geographically restricted to the snow zone, vulnerable to pest and diseases or changes in the fire frequency, and often composed of very small stands (e.g. < 2 acres in size).

Identifying strategies for improving resilience for specific forest types are beyond the scope of this analysis. However, the following recommendations have broad relevance for addressing climate change impacts to vegetation communities in the study region:

- Given the uncertainty in how forest communities will respond to climate change, the region would benefit from a robust **forest monitoring network**. For example, the Forest Service's Forest Inventory Analysis (FIA) plot network should be assessed, and potentially expanded, to evaluate health and regeneration in the most vulnerable plant populations, such as western white pine (*Pinus monticola)*, whitebark pine (*Pinus albicaulis)*, subalpine fir (*Abies lasiocarpa)*, pacific silver fir (*Abies amabilis)*, foxtail pine (*Pinus balfouriana)*, Engelmann spruce (*Picea engelmannii)*, and Alaska yellow-cedar (*Cupressus nootkatensis)*. If existing plots are insufficient, it may be helpful to increase the permanent plot network. This data is important to help inform when and where interventions may be warranted.
- The identification and **protection of mesic microclimates** that could serve as climate refugia would be a cornerstone of a regional plant conservation strategy. However, understanding of ecological requirements of target species and the hydrologic processes that create and sustain mesic areas on the landscape remains incomplete and required additional study (McLaughlin et al. 2017).
- Climate adaptations strategies also would benefit from an **inventory of high quality seed sources** for revegetation or resilience plantings. Off-site plantings (i.e., planting trees outside of their range our outside of their seed zone) should be avoided or used with extreme caution, especially in coastal areas, so as not to promote unintentional disease development (Agne et al. 2018, Wilhelmi et al. 2017). For example, the offsite planting that occurred following the Tillamook burn (1933) are attributed to stimulating a Swiss needle cast epidemic in western Oregon (Hansen et al. 2000).
- Activities and policies that **reduce stand density**, including managed wildlife, prescribed fire, and pre-commercial and commercial thinning programs, are likely to benefit regional forest health and resilience. As with most forests in California, study region forests have undergone stand densification following decades of fire suppression. Forest densification can result in competition for water and nutrients and over time can result in tree stress and mortality (Kolb et al. 2016).
- Maintain vigilance on **native pest and disease expansions and non-native pest and disease introductions** as these introductions can magnify stand level mortality and severity of impacts. For example, sudden oak death has been shown to have a synergistic effect that has increased wildfire residence time and compounded negative effects on redwood tree survival (Metz et al. 2013). New pest or diseases introductions are difficult to anticipate and can radically challenge forest management options.

Finally, for climate level resilience it is important to be flexible and adaptive. Not all actions are warranted everywhere and what works in one forest type may not be appropriate in all forest types.

WILDLIFE

The North Coast region is home to a diverse array of native wildlife species, including mammals, birds, reptiles, and amphibians, many of which are endemic to California. The region also includes a large number of threatened and endangered vertebrates, listed under the federal and/or California Endangered Species Act. Climate change is expected to have significant direct and indirect effects on wildlife. Projected changes in vegetation communities will alter the spatial and temporal distribution of habitat and food resources. Prolonged dry seasons and increasing frequency of drought years will limit access to water. Extreme weather events, including wildfire and floods, will also impact wildlife populations.

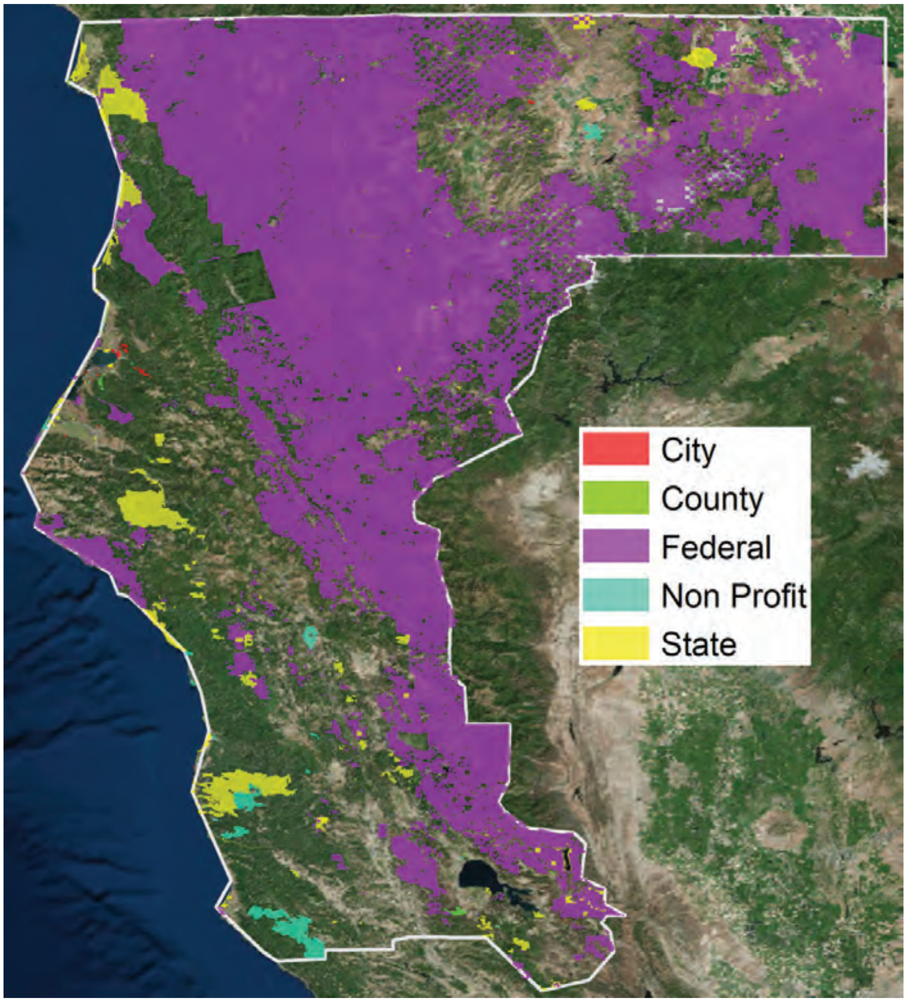
The direct impacts of climate change on wildlife will interact with non-climate factors, including land use change, the spread of pests and pathogens, and invasive species. Patterns of low-density rural residential development common to the region fragment contiguous wildland areas and can affect the movement, behavior, and health of wildlife, particularly large migratory mammals such as deer, bear, and mountain lion. The boom of cannabis cultivation in the North Coast region has caused significant environmental impacts, including the dewatering of streams, water pollution, and forest fragmentation (Carah et al. 2015), and may reduce the resilience of wildlife to climate change. Cannabis production affects wildlife communities directly through the use of rodenticides, insecticides, and fertilizers, and indirectly through habitat conversion and fragmentation (Gabriel et al. 2018, Gabriel et al. 2015, Wang Ian et al. 2017). These impacts adversely affect animal fitness and survival, as well as their behavior and movement (Carah et al. 2015, Gabriel et al. 2012). Studies have suggested that climate change will enhance the spread of disease, such as chytrid fungus that has decimated amphibian populations (Clare et al. 2016, Pounds et al. 2006), and benefit invasive species in terrestrial and aquatic environments (Hellmann et al. 2008, Rahel and Olden 2008). As wildlife species move to new locations to track shifting habitat, novel interactions with other plant and wildlife species, coupled with increasing human-wildlife conflict, may have significant effects at both the population and ecosystem level.

There are several strategies for mitigating the impacts of climate change on wildlife. Conservation planning is essential for identifying areas of the landscape that are disproportionately important in supporting regional biodiversity or species of particular management concern. For example, Olson et al. (2012) identified over 50 high-priority areas that would serve as "microrefugia" from climate change impacts for the region's endemic and vulnerable species. Such refugia have been defined as "areas relatively buffered from contemporary climate change over time that enable persistence of valued physical, ecological, and socio-cultural resources" (Morelli et al. 2016). Examples include river corridors, mature forests, north-facing slopes, and in places with cold springs and persistent wet areas that can offer favorable conditions despite an increasingly hostile, surrounding environment.

The potential to conserve wildlife under a changing climate is enhanced by the region's large coverage of publicly-owned lands, which are at least in part managed for biodiversity protection (**Figure 3.2**). However, some of the areas critical to sustaining wildlife populations occur outside of the existing protected area network (Olson et al. 2012, Howard et al. 2018). Establishing new protected areas or working with private land owners to manage lands in ways that are protective of sensitive wildlife is necessary.

Maintaining landscape connectivity is also essential for increasing the resilience of wildlife populations to climate change. To adapt to climate change, many of California's species will need to shift their distributions. Landscape planning for climate resilience should focus on maintaining and restoring habitat corridors that can facilitate species range shifts by linking protected areas to sites that will offer suitable conditions under future climates. Managing wildlife habitat corridors will require new partnerships between resource agencies, municipal and county governments, and private landowners. Such regional collaborations can be facilitated by developing a common vision of connected landscapes, articulating the multiple benefits of corridors, and involving the public in corridor planning and conservation. Scientific data, such as identifying animal movement paths, and connectivity models are also important for siting and justifying connectivity projects. California's Fourth Assessment report "Migration corridors as adaptation to climate change" by Keeley et al. (2018) provides recommendations for selecting climate-wise modeling approaches and provides practical guidance for corridor planning. For example, their framework has been applied in the "Building Habitat Connectivity for Climate Adaptation" project, which integrates habitat mapping, threat assessment, and climate change projections to enhance connectivity and climate resilience in the Mayacamas to Berryessa Coast Ranges, spanning Napa, Sonoma, Lake and Mendocino counties. The project is evaluating terrestrial and riparian connectivity across the study region to generate linkages between existing protected areas, then determining climate connectivity across the protected area network by calculating the climate benefit offered by each linkage (e.g. connecting warmer to cooler locations).

FIGURE 3.2



Protected areas by owner-entity class in the North Coast region (Source: GreenInfo Network 2017).

Freshwater and Estuarine Ecosystems

RIVERS AND STREAMS

Freshwater habitats such as rivers and streams are particularly vulnerable to climate change. Projected changes in precipitation patterns, including an increase in precipitation variability and intensity, coupled with rising temperatures, will alter streamflow regimes and degrade water quality conditions for freshwater species. The prolonged duration and increased severity of dry season low-flows (see "Streamflow and Flooding" section, above) will be challenging for cold-water dependent species such as salmon and trout. California's native salmon and steelhead are already among the most threatened fish populations in the state and a recent report by Moyle et al. (2017) concluded that 74% (23 of 31) of the remaining species are likely to be extinct in the next 100 years as a result of climate change. These include several vulnerable salmon species in the North Coast region (**Table 3.1**).

Non-salmonid species are also vulnerable to climate change. Moyle et al. (2013) performed a vulnerability assessment of the state's fish fauna and found that 82% of native taxa (100 of 131) were highly vulnerable to climate change. In contrast, only 19% of non-native fish (8 of 43) taxa were considered vulnerable to climate change, suggesting that stream fish communities will become increasingly dominated by non-native species in the future.

TABLE 3.1

SPECIES	LEVEL OF CONCERN
California Coast Chinook salmon *(O. tshawytscha)*	high (2.9)
Southern Oregon/Northern California Coast Chinook salmon *(O. tshawytscha)*	moderate (3.1)
Upper Klamath-Trinity Rivers fall-run Chinook salmon *(O. tshawytscha)*	moderate (3.1)
Upper Klamath-Trinity Rivers spring-run Chinook salmon *(O. tshawytscha)*	critical (1.6)
Central California Coast Coho salmon *(O. kisutch)*	critical (1.3)
Southern Oregon/Northern California Coast Coho salmon *(O. kisutch)*	critical (1.6)
Chum salmon *(O. keta)*	critical (1.6)
Klamath Mountains Province summer steelhead *(O. mykiss irideus)*	critical (1.9)
Klamath Mountains Province winter steelhead *(O. mykiss irideus)*	moderate (3.3)
Northern California summer steelhead *(O. mykiss irideus)*	critical (1.9)
Northern California winter steelhead *(O. mykiss irideus)*	moderate (3.3)
Coastal Cutthroat trout *(O. clarkii clarkia)*	high (2.7)
Coastal rainbow trout *(O. mykiss)*	low (4.7)

Level of conservation concern for unique salmon and trout species in the North Coast region. Species are ranged on 5-point scale indicating the level of concern over the extinction risk of each species as low (4.0 – 5.0), moderate (3.0 – 3.9), high (2.0 – 2.9), and critical (1 – 1.9) (Source: Moyle et al. 2017).

The current threatened state of many of California's freshwater species populations also makes them vulnerable to extreme disturbance events, including floods, wildfire, and debris flows. Heavy rainfall can scour stream channels, initiate landslides, and deposit large volumes of sediment into river channels. Excessive sediment is already a problem for North Coast streams, nearly all of which are listed as impaired for sediment under section 303(d) of the federal Clean Water Act. Elevated sediments degrade spawning habitat for salmon and other species and reduce the diversity of benthic macroinvertebrates, the primary food source for stream fishes.

KLAMATH RIVER SALMON MANAGEMENT IN A WARMING CLIMATE

Andrew Stubblefield

An illustrative example of how climate change might exacerbate conflicts between fish and people is the 2002 Klamath River Fish Kill. Under pressure from Vice President Richard Cheney, dam operators delivered the full allocation of water to upstream ranchers and farmers despite drought conditions and the warnings of fish biologists. The atypical low flow in the river along with high fish return numbers and high water temperatures allowed for a gill rot disease to kill over 30,000 adult Chinook salmon returning to the Klamath River to spawn in September 2002 (Guillen 2003). This was the largest fish kill in the history of the western United States. Increased temperatures, altered rainfall, and declining snowpack could make the conditions and conflicts that led to this tragedy much more likely to occur in the future.

Dead salmon in 2002 on the Klamath River near Klamath Glen, CA (Photo: Shaun Walker/The Times-Standard)

Numerous efforts by tribes, environmental organizations, and state, local, and federal agencies are underway in northern California to improve conditions for the region's iconic salmonid populations. The same restoration techniques that are being implemented now to help dwindling fish populations will help fish adapt to changing conditions from climate change. For example, on the Salmon River, a tributary to the Klamath River and a major stronghold for wild spring-run Chinook populations, efforts are underway to re-connect and restoring winter and summer rearing habitats. Field crews are opening up tributaries for spring Chinook to access additional spawning and rearing habitat by manually enhancing fish passageways. Historically, as noted through oral tradition, spawning and rearing took place largely in the creeks.

Further efforts include enhancing these spawning and rearing habitats by adding cover and complexity with woody debris and riparian vegetation and monitoring the population size and health through adult and juvenile fish surveys.

Reconnecting floodplains to the stream channel may be one of the most effective restoration actions to counteract climate change. Alcoves and off-channel habitats allow for interaction of surface water with the underground water table, allowing it to cool and resurface as cold seeps and springs. Reconnecting floodplains also allows for a healthier community of riparian plants and trees, providing shade to protecting the stream from direct solar radiation.

The removal of migration barriers, including culverts, lowhead dams, road and rail crossings, etc., is another important strategy for countering the effects of climate change, by allowing species the ability to expand their range and access historical habitats, especially in upper watersheds where water temperatures are generally more favorable for salmon and other cold-water fishes.

Maintaining healthy river ecosystems and conserving sensitive fish species in the face of climate change requires a multi-faceted approach. River ecosystem management would benefit from a planning framework that prioritizes protection of pristine streams and restoration of productive floodplain habitats that support fish growth and survival. Similar to wildlife conservation strategies, the identification and protection of "climate microrefugia" in stream ecosystems is also important. For example, the protection of headwaters and streams that receive substantial cold-water inputs from springs or groundwater sources will be essential for supporting salmon in a warming climate (Isaak et al. 2015). The protection and restoration of riparian vegetation along river channels can also play an important role in reducing solar radiation and water temperature warming. Finally, the release of adequate flows below dams for fish and strategic removal of fish passage barriers will be important for allowing fish to freely move through stream networks in response to stressful environmental conditions.

CLIMATE CHANGE AND HARMFUL ALGAL BLOOMS IN CLEAR LAKE

Angela De Palma-Dow and David Cowan

Lake County's most prominent ecological and economic feature is Clear Lake. With over 100 miles of shoreline, Clear Lake is the largest, natural freshwater lake in California and one of the oldest lakes in North America. A tourist and visitor destination, Clear Lake is popular for all water-related activities including fishing, swimming, boating, and water-skiing. Ranked as one of the top three bass fishing destinations in the continental US, Clear Lake relies heavily on the tourism dollars brought in by fishing and other recreational activities. For example, resident and non-resident angling alone is estimated to generate $1 million annually (Giusti 2016), underscoring the importance of Clear Lake to the regional economic stability of the county.

Spring time view of Clear Lake with Mount Konocti in the background (Photo: Lake County Department of Water Resources)

Clear Lake is a shallow, warm, and historically eutrophic lake, highly susceptible to changing temperatures, winds, and nutrient inputs. While high primary productivity is a historical norm for Clear Lake, the occurrence of Harmful Algal Blooms (HABs), measured by cyanobacteria toxin concentrations that exceed state health limits of 0.8 ppb (California Environmental Protection Agency 2012), can impact the visitation rate and recreation integrity within Lake County. In 1994, it was estimated that the region lost an estimated $7 million in revenues and associated spending due to lower visitation to Clear Lake owing to HABs and poor water clarity (Richerson et al. 1994).

Algae and cyanobacteria growth is driven by three major components; sunlight, nutrients, and warm temperatures. When all these conditions are met, growth can be exponential. During warm days, cyanobacteria colonies can reproduce at high levels, becoming visible as bright green scum layers, globs, or foul-smelling mats. Cyanobacteria HABs are especially hazardous because they produce toxins that, if consumed, can cause severe health effects in humans and sickness or death for pets, fish, and wildlife.

Climate change is likely to increase the risk of HABs in Clear Lake. Surface temperatures (<1m depth) have been warming over spring and summer seasons, with an average change of 0.64 °C every year since 1968, based on data collected by California Department of Water Resources[3]. In addition to increasing temperatures, algae and HABs occurrence is driven

3 Accessed through the Water Data Library at http://wdl.water.ca.gov/waterdatalibrary/

by excess nutrients, specifically phosphorous, entering the lake from both point and non-point sources. There is a strong spatial association between areas of excess nutrients, algal growth, and high cyanobacteria concentrations. Increasing water temperatures, in combination with nutrient inputs such as phosphorous, will create conditions more conducive to cyanobacteria HABs (Paerl and Huisman 2009).

Strategies to control HABS focus on limiting the factors that stimulate growth. While temperature regulation is nearly impossible on such a large, shallow lake, nutrient inputs can be managed. The Lake County government, local tribes, the state, and multiple federal agencies have collaborated on efforts to reduce and retain sources of nutrients flowing into Clear Lake. For example, the Middle Creek Wetlands Restoration Project, which will restore 1400 acres of wetland to north Clear Lake near Rodman Slough, aims to achieve a 40% phosphorous reduction goal. Wetlands are nutrient and carbon sinks, providing a "filter" for lakes, cycling and storing nutrients and improving water quality. Past efforts to reduce nutrient loads have been relatively successful over the last few decades, but the current and future management efforts may be less effective if warming temperatures continue, increasing economic burdens and ecological uncertainty for the future of Clear Lake.

A boat wake through the algal mats during 2011 in the Lower Arm of Clear Lake, CA (Photo: Lake County Department of Public Works)

COASTAL WETLANDS AND ESTUARIES

Sea-level rise represents a significant threat to coastal wetland and estuarine ecosystems and the species that inhabit them. Thorne et al. (2018) evaluated the impacts of sea-level rise on tidal wetlands in estuaries along the US Pacific coast and, according to higher-range sea-level rise scenarios, predicted the complete loss of coastal marsh habitats and conversion to mudflats at southern Oregon and northern California study sites. This research did not evaluate potential wetland habitat conversion in Humboldt Bay, but other local studies suggest that rising tide heights from sea-level rise and land subsidence would inundate marsh and wetlands habitats which are particularly important for birds (see "Sea-level rise" section, above). However, these impacts may be partially offset by the inundation of former bayland habitats that are currently located behind lowhead dikes. Additional information on climate change impacts to coastal ecosystems is provided in Coasts and Oceans topical report in the Fourth Climate Assessment (Phillips et al. 2018).

Rangelands and Agriculture

The potential impacts of climate change on agriculture in the North Coast has received limited attention. However, increasing variability and uncertainty in timing and quantity of precipitation is expected to significantly affect agricultural and rangelands (Byrd et al. 2015, Shaw et al. 2011). Less reliable water supplies, coupled with increasing soil water deficits, will make it more difficult to satisfy irrigation demands for crops and pastures. An overall reduction in rangeland quality is expected, as current trends of woody encroachment continue and increasingly arid conditions promote the distribution and abundance of late-phenology rangeland weeds, such as yellow star thistle (*Centaurea solstitialis*), Barbed goatgrass (*Aegilops triuncialis*), and Medusahead (*Taeniatherum caput-medusae*). In the short term, increased use of herbicides may be required for invasive species and weed control on rangelands. The incorporation of drought-tolerant varieties into forage seed mixes, and warm-season grasses for pasture mixes, could also help off-set reductions in forage quality for livestock producers. In the long-term, greater use of prescribed fires is likely the best tool for late-phenology weed control and for reducing the risks of uncontrolled wildfire. It is likely, however, that woody encroachment will continue throughout the coastal range and management efforts to reduce encroachment are unlikely to reverse current or future losses of grasslands. As woody plants encroach on rangelands, a subsequent increase of soil carbon storage will occur in those traditionally grass-dominated systems (Silver et al. 2010). However, potential for larger, more intense wildfire increases with the increased fuel load.

Although modeling in Silver et al. 2018 suggests that rangeland composting could increase long-term soil carbon stocks on agricultural lands, such treatments would likely be cost-prohibitive and logistically challenging to administer on North Coast rangelands. Low population densities and the long distances of most pasturelands from populated areas limits access to sources of compost and fertilizer. Steep topography also presents practical challenges of spreading compost or other carbon-rich soil amendments. Finally, the economic benefits of increased forage protein values may be more beneficial in annual rangelands than in the North Coast's mixed perennial rangeland systems.

Meanwhile, irrigated beef and dairy operations on the coast may rely more on silage corn if decreasing fog and precipitation reduce cool-season forage growth and increase potential for short-season silage corn. It is also likely that, on prime agricultural soils, crop diversities will increase with increased temperatures and longer growing seasons. Prime agricultural lands and dairy operations in the low-lying areas around Humboldt Bay and the Eel River delta are also threatened by sea-level rise. Sea-level rise will significantly increase the frequency and extent of inundation in low-lying areas, particularly if levees fail (see "Sea-level rise" section, above, and "Humboldt Bay and Sea-level rise" box, below). However, even if levees are maintained or enhanced, recent research suggests that coastal plains in the region are susceptible to inundation from groundwater as rising sea levels drive the emergence of shallow groundwater to the surface (Hoover et al. 2017).

The effects of climate change on the cannabis industry are likely to be small relative to the effects of recent major shifts in cannabis regulation. Since state legalization of recreational cannabis use with the passage of Proposition 64 (2016) and legal sales starting in January 2018, land values in remote centers of the region (where cannabis has traditionally been cultivated) have plummeted along with decreased cannabis value, with these trends forecasted to continue. Many assume that cannabis production will continue in these counties, but that the majority of cannabis farms will be retired and that some will move to lower elevation, traditional agriculture soils or continue in greenhouses and indoor farms. However, the future of cannabis on the North Coast remains highly uncertain.

NORTHERN CALIFORNIA VINEYARDS AND CLIMATE CHANGE

Glenn McGourty

Mendocino County vineyard (Photo: Coolcaeser/Wikipedia)

Wine grape and wine production are major contributors to Mendocino and Lake County's economy and are increasingly important agricultural products in the North Coast region. Lengthening of the dry summer season, increased temperatures, and greater frequency of drought years expected under climate change will deplete water storage in vineyard soils and reduce water supplies needed for irrigation and frost protection. Vine vegetative growth, fruit set, and yield are all reduced during dry years. Extreme summer heat waves damage fruit, causing burns that inhibit pigment formation in grape skins, lowering cluster weight, and reducing fruit quality and yield. Often, there are more frost events in the spring of dry years as dew points are much lower and radiant freezes are more likely to happen. In the very dry year of 2008, there were over 20 frost protection events in the Ukiah area of Mendocino County. Many vineyards relying on surface water stored in small ponds for sprinkler frost protection ran out of water for irrigation by the end of the growing season. Under drought conditions, fruit is likely to dehydrate, increasing sugars beyond optimal wine making levels, and reduced acid may also require amelioration in the winery. Finally, long, warm growing seasons may increase the number of generations of common insect pests such as Western Grape Leafhopper, Virginia Creeper Leafhopper, and Pacific mite. With more growing degree days, insects are able to develop earlier and later in the season, increasing the need to apply more pesticides.

A combination of drought and high temperatures has resulted in several recent deadly wildfires in the North Coast region. In 2008 (Mendocino Lightening Complex Fire), 2015 (Lake County Valley Fire), 2016 (Lake County Clayton Fire), and 2017 (Mendocino Redwood Fire, Sonoma County Tubbs Fire, Napa Atlas Fire and the Lake County Sulfur Fire), significant wild fires destroyed property, killed people, livestock, and pets, and released dense smoke that engulfed the region. It is becoming more common for hot spells to occur in the fall along with on-shore or land breezes, creating very low humidity and high winds which can fan wildland flames into more destructive fires. Drought stressed and dead trees provide fuel. While actual destruction of vineyards by fires has been limited, the potential damage to fruit and wine from smoke can be significant. Enzymes found in the grape vine, called glycosyltransferases, bind grape sugars to the smoky volatiles in the air primarily in the skins of the fruit. The volatile compounds are released during fermentation by hydrolysis, creating off flavors in the wine. It may be possible to mitigate this in white wine (since skin contact is minimal in the winemaking process) but it is very difficult with red wine making due to the need for prolonged skin contact during fermentation. Significant economic losses have occurred from smoke flavors in wine.

Climate Change Vulnerabilities and Adaptation Strategies for Communities

In this section, we consider threats to social systems and the built environment in communities of the North Coast Region. We examine vulnerabilities to the regional transportation network and other critical infrastructure, including water supply systems, energy and communication networks, and wastewater treatment facilities. We also discuss the impacts of climate change on public health, emphasizing risks to vulnerable communities.

California's transportation, energy, and water infrastructure was designed to accommodate its highly variable climate, but it is frequently disrupted by natural disasters. Climate change will directly and indirectly exacerbate these disasters in the North Coast and introduce new challenges, such as rising sea levels and inundation of critical infrastructure in the coastal zone. Infrastructure failures will disrupt regional economic activity, cut-off critical emergency and public transportation services, and impact the quality of life for all of the region's inhabitants. The economic costs of reducing vulnerabilities of regional infrastructure through repairs, reinforcement, and relocation is likely to be high and will also place a significant burden on the regional economy.

Humboldt Bay and the City of Eureka (Photo: Robert Campbell/U.S. Army Corps of Engineers)

The impacts of these and other climate-driven disruptions will be disproportionately experienced by vulnerable populations in the North Coast Region. These include but are not limited to: low-income individuals, families, and people of color, women, the young, the elderly, people with disabilities, people with existing health issues including mental health issues, and people with limited-English proficiency. These populations will often not only feel the immediate impacts of climate change more significantly, but also are less able to adapt to climate changes or recover from their impacts.

This situation, where environmental justice intersects with climate impacts, adaptation and resilience is called climate justice. Climate justice is the theory "that no group of people should disproportionately bear the burden of climate impacts or the costs of mitigation and adaptation" (Cooley 2012). Much research has been dedicated to estimating the impacts of climate change; less research has been done on how to implement climate adaptation strategies and build climate resilience for and with vulnerable communities. Adaptation strategies need to account for and include communities that have fewer social and economic resources to prepare for, adapt to and recover from the effects of climate change. Additional information on climate justice and climate change impacts to vulnerable communities in California is provided in the Climate Justice topical report of the Fourth Climate Assessment.

Transportation Network

Roadways in the North Coast study region traverse a topographically diverse landscape with unstable geology that regularly produces landslides and hillslope failures. Coastal highways are particularly vulnerable to landslides and beach erosion hazards. Sea-level rise and more intense coastal storm surges will increase the vulnerabilities of coastal transportation routes. Existing infrastructure protections may require fortification and road segments previously not-at-risk will become vulnerable.

In 2014, the California Department of Transportation (CalTrans) completed a climate change vulnerability assessment for the transportation network for District 1 (Del Norte, Humboldt, Mendocino, and Lake Counties), which evaluated nearly 1,000 miles of 23 roadways (CalTrans 2014). The most vulnerable road segments in the region were identified by combining stakeholder-driven assessments of "criticality" (how important the road is to economic activity) and potential for impact (the likelihood of reduced capacity, temporary failure, or complete failure). As part of the study, they also evaluated the vulnerabilities and adaptation options for pilot projects in each county. These included roads along Humboldt Bay that are vulnerable to sea-level rise and flooding, a section of Highway 101 known as "Last Chance Grade" in Del Norte County (see Box, below), a section of Highway 1 in coastal Mendocino County, and a section of Highway 20 in Lake County.

Overall, the assessment concluded that the majority of the road network had low vulnerability to climate change, but several road segments were considered at risk, having both high criticality and a high potential for impact. Among the vulnerable road segments, high criticality scores were related to their limited redundancy (i.e., lack of alternative road routes) and presence of infrastructure assets such as bridges and stormwater facilities. Coastal erosion hazards, tidal inundation risk, chronic landslides, and drainage challenges were the factors contributing to sites receiving "potential high impact" scores. Adaptation options for pilot projects were discussed and scored through a public process. The relative costs of project alternatives, as well as the estimated useable life, level of performance, and social and environmental impacts, were assessed. In general, the assessment determined that adaptation options for each of the projects would require between $50M and $1B in capital investment. The vulnerability assessment also exposed the value of directly engaging with stakeholders to understand the dependencies between CalTrans assets and the interests of local public and private entities. Local input is essential for setting regional priorities and building support for investment in climate-adaptation projects in the transportation system.

A climate change vulnerability assessment for CalTrans District 2 (including Siskiyou and Trinity Counties) has not yet been conducted. Vulnerabilities to the extensive network of non-CalTrans maintained roads that serves most of the region's rural population have also not been assessed. These county, municipal, and private roads traverse some of the most rugged landscapes in the state, yet little is known about their vulnerability to climate change and how failures could affect local residences and communities. The entire road network would benefit from a transportation vulnerability assessment using a similar impact-criticality framework to guide regional priorities for maintenance and investment.

LAST CHANCE GRADE SLIDE

Andrew Stubblefield

Increasing rainfall intensity resulting from climate change has the potential to trigger unstable landslides that traverse northern California's road transportation network. By undercutting the base of coastal bluffs, sea-level rise further increases the instability of coastal roads. The Last Chance Grade slide is an example of the challenges facing the region and the magnitude of costs that could be incurred as heavy rainfall becomes more frequent, sea levels rise, and coastal erosion accelerates.

Gully erosion at Last Chance Grade, Highway 101, Del Norte County (left panel) and diagram of processes affecting the site (right panel) from CalTrans (2014)

Nine miles south of Crescent City, Highway 101 traverses a region with hundreds of landslides. The stretch of highway currently requires $2M in yearly maintenance costs to keep the road open. Caltrans has spent $67M on the Last Chance Grade since 1980. Heavy rains in March 2016 and the winter of 2017 led to cracks and settling on the roadway, deformation of retaining walls, and a localized landslide that took out the southbound lane at mile post 14.4. Repairs to this storm damage will cost $27.6M. The potential exists for a larger slide to completely remove sections of the road, effectively cutting off Crescent City and rural northern communities from the rest of the state and causing major economic damage to the region. CalTrans is currently evaluating options to build an alternate route around the slide. Costs for the different options run from $240M to $1B dollars. Maintaining the existing alignment would appear to be the most cost-effective option, but if a large slide occurs, the economic costs to the region could greatly exceed the costs of realigning the road. Will state and federal funds be sufficient for this work if damage to transportation networks becomes more frequent and extensive across California?

For more information, see: http://www.lastchancegrade.com

Water, Energy, and Communications Infrastructure

Most municipalities in the region rely on surface water supplies from large rivers, including the Eel, Klamath, and Mad River systems, or from local groundwater sources. The relatively low water demands of municipal users relative to supplies (DWR 2015), and absence of critically over-drafted groundwater basins (DWR 2016a), suggests that communities are not highly vulnerable to drought. However, there is potential for wildfire, floods, and other natural disasters to temporarily disrupt water supply systems. Rural residential communities that rely on local surface water supplies and wells face greater water scarcity risks. Shifts in precipitation regimes towards shorter winters and prolonged dry seasons, coupled with increased frequency of drought, may limit water supplies from local sources. Unpermitted diversions from cannabis may compound the risk of water scarcity. Improved permitting and enforcement by the State Water Board and efforts to increase local water storage capacity for rural residential water users should help improve their water security.

A formal assessment of the vulnerability of the region's water, energy, and communications infrastructure has not been conducted. However, all of these systems are threatened to some degree by natural disasters that are intensified by climate change, including floods, wildfire, and sea-level rise. Infrastructure vulnerability assessments have been conducted in other regions of the state and should also be performed in the North Coast region. High priority should be given to the evaluation of the region's disaster planning and emergency response systems, which tend to be less robust in rural areas with limited communications and energy networks, but are essential to limiting economic damages and the loss of life during and after natural disasters.

Critical infrastructure assets in the Humboldt Bay region are at risk from rising sea levels, including wastewater treatment plants and storm water facilities (see "Humboldt Bay and Sea-level rise" box, below). Under modest sea-level rise scenarios, failure of dikes and levees surrounding Humboldt Bay would overwhelm the City of Eureka's waste water treatment plants, water transmission lines, natural gas lines, and other valuable assets (Laird 2016). The City of Arcata's wastewater treatment facility is also at risk (Laird 2013). The California Coastal Commission (CCC) has facilitated public meetings to identify local and regional priorities and discuss opportunities for advancing sea-level rise planning and adaptation projects (CCC 2016). However, the pace of assessment and implementation remains slow and may result in increased economic disruption and cost if communities are reactive rather than proactive in addressing the threat of sea-level rise.

Several options for reducing the impacts of sea-level rise to infrastructure exist, such as reinforcing or building new tidal barriers, raising the ground elevation of assets in their current location, or relocating vulnerable assets to higher elevation, inland locations. The relative costs of these alternatives will depend on the local context and design features and are difficult to generalize, but each has distinct social and environmental consequences that must be considered. Given that decisions will be complicated by uncertainty in future sea-level rise conditions, prioritization should be given to "no-regret" strategies (Hallegate 2009). These are options that have relatively low cost and yield benefits even in the absence of climate change, for example, land-use and building restrictions within flood-prone areas, investment in insurance, warming, and evacuation schemes, and enhanced drainage systems.

Planned retreat, also known as strategic retreat, refers to the managed removal and relocation of development threatened by rising sea levels, which can be triggered by threshold indicators (Eastern Research Group 2013).

This involves the identification of vulnerable properties and assets and then developing incentives, such as regulatory, tax, and market-based tools to encourage and achieve realignment (Reza Environmental and Tinsman 2018). Land use planning and regulations by local governments and agencies such as the California Coastal Commission can also play an important role in facilitating planned retreat and other adaptation strategies to address sea-level rise (Herzog and Hecht 2013).

Where new or improved infrastructure is needed to protect structures and other assets, there is growing interest in the use of natural infrastructure for shoreline protection as an alternative to traditional armoring approaches (Newkirk et al. 2018). In this context, natural infrastructure means using nature to reduce the vulnerability of coastal communities to climate change related hazards and to increase the long-term adaptive capacity of coastal areas. Examples of natural shoreline infrastructure include restored sand dunes, marsh sills, and oyster reefs. Natural infrastructure promotes the ability of natural systems to respond to sea-level rise and migrate landward and can play an important role in planned retreat strategies. Natural infrastructure is often more cost-effective than traditional armoring approaches (Newkirk et al. 2018), and may also provide important co-benefits for coastal communities, such as serving as protective buffers against sea-level rise and storm events while continuing to provide access, recreation opportunities, and other social benefits that coastal ecosystems provide. These benefits have been well documented (e.g., Barbier et al. 2011, Gedan et al. 2011, Moller and Spencer 2002, Narayan et al. 2016, Shepard et al. 2011, Wamsley et al. 2015).

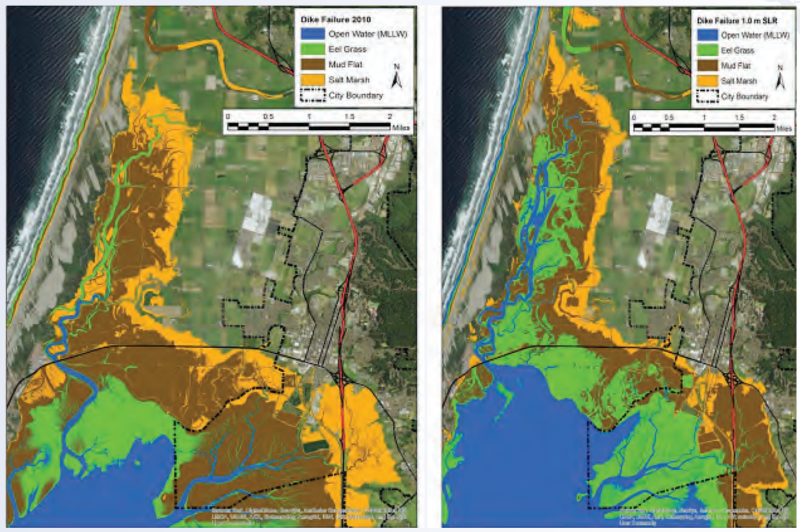
SEA-LEVEL RISE AND HUMBOLDT BAY

Aldaron Laird

Humboldt Bay has 102 miles of shoreline, 75 percent of which consists of man-made barriers, such as dikes and bulkheads. Approximately half of the shoreline barriers protect thousands of acres of low-lying areas from regular tidal inundation. Eroding dike structures are at risk of breaching under current sea level and tidal regimes. The consequences of a dike breach could be significant, potentially tidally inundating thousands of acres of former tidelands. These areas are primarily pasture and seasonal freshwater wetlands, but also include critical infrastructure assets, including roads, water pipelines, electricity towers, Eureka and Arcata's wastewater treatment plants,

Dike overtopped during a king tide tidally inundating low-lying lands in southern Humboldt Bay (Photo: Aldaron Laird) and the Humboldt Bay Power Plant and spent nuclear fuel storage facility.

Currently, there are 3.3 miles of diked shoreline that are vulnerable to being overtopped by king tides. With one foot of sea-level rise, king tides could place 11.4 miles of diked shoreline at risk of being overtopped, and with two feet of sea-level rise, 23.4 miles could be overtopped. A New Year's Eve 2005 king tide and storm surge caused sea levels to rise 1.8 feet, the highest water level ever recorded on Humboldt Bay, and prompted the Governor to declare a State of Disaster. King tides could reach the tipping point of between two and three feet as early as 2050, based on current high projections for sea-level rise.



Inter-tidal inundation extent of northern Humboldt Bay if dikes are breached under current conditions (left panel) versus with three feet of sea-level rise (right panel) (Source: Laird 2018).

If the diked shoreline were compromised today, Humboldt Bay could expand to 30,308 acres. Sea-level rise of three feet would increase the bay to 33,451 acres (63.5% greater than its current size), eel grass habitat could expand 1,269 acres (22.0%), mud flats 5,984 acres (119.4%), and salt marsh 2,948 acres (190.8%). Nearly two-thirds of the agricultural land in the Coastal Zone around the Bay could be tidally inundated with three feet of sea-level rise. The communities of King Salmon, Fields Landing, and Fairhaven in the unincorporated area of the County could also become tidally inundated. With three feet of sea-level rise, the most vulnerable asset in the City of Arcata is its wastewater collection system and treatment facility at the Arcata Marsh. At high tides, backup of the City's stormwater drainage systems could result in flooding farther inland, even in areas protected by dikes. Eureka's wastewater treatment plant is also vulnerable, and with 3 feet of sea-level rise, a significant portion (80%) of the city's Coastal Zone could also become tidally inundated, threatening land uses and developments, utilities, transportation infrastructure, coastal resources, and public access.

Around Humboldt Bay, the State has retained jurisdiction over development on approximately 75% of the Coastal Zone, on existing and former tidelands. The Coastal Commission is not bound by Local Coastal Program policies and adheres to the Coastal Act in review of proposed developments. The challenge of adaptation planning for sea-level rise on Humboldt Bay will be for Local Coastal Program authorities (Humboldt County, City of Eureka, and City of Arcata) and the Coastal Commission to integrate the application of their authorities to effectively and efficiently address the impacts of sea-level rise on coastal resources and developments.

Wildfire Management

There is growing recognition that active vegetation management, including thinning and prescribed fire, will be critical for reducing fire risk to communities and conserving the cultural and ecological values of the region. Thinning and fire are needed to reduce stand densities and fuel loading in most of the region's forest types. Prescribed fire would also benefit grasslands by controlling late-phenology invasives and promoting species of interest. Thinning and fire in oak woodlands can help to reduce conifer encroachment and to maintain open stand structure. Prescribed fire presents a number of potential benefits for the region, including fuels reduction, cultural resource management, habitat restoration, range improvement, and drought resilience. Recent research has shown that prescribed fire can be used to promote forest resilience during wildfire, but also to decrease mortality from drought by reducing stand densities and competition for resources (van Mantgem et al. 2016).

Several models of successful community-based fire adaptation are emerging in the North Coast. Examples include the mid-Klamath corridor in Humboldt and Siskiyou counties, where collaborative processes are enabling communities and agencies to work together on strategic fuels projects that buffer communities from adjacent wildlands (see "Building capacity for prescribed fire" box, below). Collaborative work is also happening in Trinity County, where community-agency partnerships are enabling large-scale fuels planning and implementation. Likewise, the recent formation of the Humboldt County Prescribed Burn Association will empower landowners and other non-governmental entities to scale up prescribed fire use in the region by working together to plan, fund, and implement prescribed burns. Similar groups are common in the Great Plains, but this is the first of its kind to form in the West. Given the challenges that lie ahead, agencies and communities in the North Coast will need to continue to find innovative, collaborative models for fire management, including cross-boundary fuels treatment efforts and cooperative approaches to capacity building. Agencies will also need to better prepare to use wildfire to meet resource objectives. This will require updating land management plans and better incorporating wildfire as a management tool (North et al. 2012), and communicating with local communities about the realities, risks, and opportunities inherent to managing fire for resource benefits.

BUILDING CAPACITY FOR PRESCRIBED FIRE

Lenya Quinn-Davidson

For the last decade, the North Coast has been a hot bed of innovation around prescribed fire capacity building and training. The Northern California Prescribed Fire Council (which formed in 2009 as the Northwestern California Prescribed Fire Council before expanding its region to encompass the entire north state) provided a novel venue for practitioners, regulators, researchers, and others to collaborate on prescribed fire challenges and opportunities. In the eight years since its inception, the Council has continued to provide a venue for networking and collaboration, policy issues, outreach and education, and training.

Prescribed burn by the Northern California Prescribed Fire Council (Lenya Quinn-Davidson)

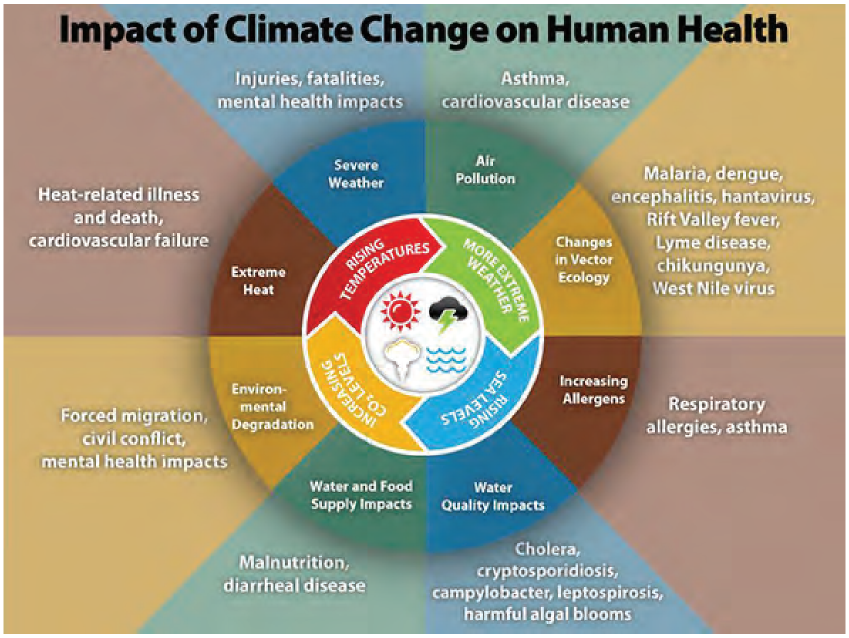
In 2013, the Council hosted the first Northern California Prescribed Fire Training Exchange, or TREX—a two-week prescribed fire training opportunity that brought people from across the country and the world and provided them with opportunities to burn and learn together in Humboldt, Trinity, and Shasta counties. The Council has continued to host the Nor Cal TREX annually, helping diverse fire practitioners—including many who would not otherwise have access to prescribed fire training—build fire qualifications and increase the capacity of their home agencies and organizations. In 2014, several organizations in the mid-Klamath region hosted a separate TREX event (the Klamath TREX). That event focused on building local capacity, and local community and tribal members were invited to participate in the training, working alongside agency and NGO staff from across the country. The Klamath TREX has also become an annual event, and it is typically hosted in the fall just before the Nor Cal TREX.

More recently, a large group of landowners, volunteer fire departments, and other non-governmental organizations have joined forces to form California's first prescribed burn association. The Humboldt County Prescribed Burn Association (HCPBA) is a cooperative group focused on planning and implementing prescribed burns on private lands, and providing a forum for training, resource and equipment sharing, and funding. The HCPBA joins many other similar groups throughout the Great Plains and surrounding regions, but it is the first of its kind in the West.

Public Health and Safety

Climate change-induced heat waves, flooding, sea-level rise, drought, wildfire, and the spread of infectious diseases pose severe risks of injury, morbidity, and mortality to North Coast communities through short-term and long-term, direct, and indirect exposures and related socioeconomic disruption (see image on right). In addition to acute risks that can result from extreme weather events such as storms, flooding, and wildfire, communities can experience air and water quality threats, outbreaks of infectious disease and post-traumatic stress, depression, and increased risk of suicide in the wake of climate-related events. Below, we outline areas of climate-related public health risks facing North Coast communities.

FIGURE 4.1



Impacts of climate change on human health (Source: Federal Center for Disease Control and Prevention 2016)

HEAT-RELATED ILLNESS

The interior zone of the North Coast region faces an increasing risk of exposure to extreme high heat days and heat waves, increasing the risk of heat-related illness and mortality from cardiovascular failure, heat stress/stroke, and dehydration (CDPH 2013). Risks to the high proportion of elderly living along in the region (English et al. 2007) are of particular concern. Agricultural fieldworkers, such as those working in Mendocino and Lake County vineyards, are especially vulnerable to extreme heat events. Increased exposure of outdoor workers to heat waves and prolonged heat days are likely to increase heat-related illnesses (Cooley 2012). Changes in work hours and efforts to limit heat exposure, including shade structures and hydration systems, will be needed to reduce these potential health impacts.

FLOOD RISK

Large storms and intense rainfall events cause flooding and increase the risk of drowning or displacement. Projected increases in sea level will increase the extent of areas vulnerable to flooding along the coast. For example, the 100-year flood inundation is projected to increase by nearly 20% in Humboldt, Mendocino, and Del Norte Counties by 2100 (Maizlish et al. 2017a, b, d). In 2010, nearly 2,000 Del Norte County residents lived on coastal blocks that were at risk of inundation from a 100-year flood (Maizlish et al. 2017a), a number estimated to grow to 3,000 residents by end of century. In Humboldt County, the number of residents vulnerable to sea-level rise is expected to more than double (from 3,700 to 7,900 residents) (Maizlish et al. 2017b). Coastal flooding poses other public health risks, such as salt water intrusion into coastal aquifers. In addition, water intrusion into buildings can result in mold contamination leading to property damage and indoor air quality problems (Luber et al. 2014).

WILDFIRE HEALTH RISKS

Increasing severity and intensity of wildfire directly threatens residences and critical infrastructure, including roads and water supply systems. Rural communities are particularly vulnerable to the risks associated with wildfire, including direct injury and death, destruction of property, and displacement. Rural communities rely on extended electricity lines through wildland areas that can cause fires (Collins 2005), and at the same time, are more vulnerable to outages in energy and communication networks from wildfire damage. Wildfires increase the distribution of particulate matter in the lower atmosphere, leading to increased hospitalizations and even deaths due to cardiovascular and asthma-related emergencies. For populations already struggling with chronic health conditions, additional exposure to smoke and fire-related particulate matter can have significant health consequences. For example, nearly half of the adult population of Lake and Mendocino Counties (49,000 people total) reported one or more chronic health conditions, including heart disease, diabetes, asthma, severe mental stress and/or high blood pressure (Maizlish et al. 2017c, d).

Smoke and particulate matter released by wildfire can affect the entire region, including communities on the coast that have limited risk of direct exposure to wildfire. Climate-informed programs that incentivize use of fire-resistant building materials, limit new construction in fire-prone areas, and encourage vegetation management in and around residences and infrastructure assets would be helpful. New approaches to wildfire management, including broader and more frequent use of prescribed fire (see "Wildfire Management" section and "Building capacity for prescribed fire" box, above) are also needed.

EMERGENCY SERVICES

Although there is no region-specific data on the status of emergency response services, California as a whole is not prepared to absorb high patient loads from climate change associated disasters (Report Card Task Force and Staff 2014). The American College of Emergency Physicians assigned California an overall emergency care grade of F (ranking 42nd among States) for access to emergency care. Enhancing emergency response, public health and clinical infrastructures in advance of crisis will save lives and reduce the societal and economic costs of climate hazards (Lauland et al. 2018).

MULTIPLE STRESSORS

Natural disasters that are exacerbated by climate change can produce ***multiple stressors*** to social systems and public health. These are defined by the increased occurrence of simultaneous or sequential exposures to environmental hazards. Individuals, populations, or communities might have the adaptive capacity and resilience to cope with a single exposure or environmental challenge; however, the cumulative impacts of multiple stressors can easily overtax biological or societal systems resulting in far more serious health consequences. The multiple stressors related to climate change may relate to lack of access to food, water, transportation, housing/shelter, and basic services as well as mental health issues due to depression, anxiety, stress, and shock from loss of family, home, livelihood, or displacement (Aitsi-Selmi and Murray 2016, Basu et al. 2017, Vins et al. 2015, Ziegler et al. 2017). As noted by Maizlish et al. (2017b), "*disruption includes damage to the infrastructure for the delivery of health services and for general economic well-being. Health care facilities, water treatment plants, and roads for emergency responders and transportation for health care personnel can be damaged in climate-related extreme weather events. Increased burden of disease and injury will test the surge capacity of health care facilities. Economic disruption can lead to income loss, income insecurity, food insecurity, housing insecurity, and mental health problems, which in turn may increase substance abuse, suicide and other health problems.*" Disruption of the transportation network from flood or wildfire, for example, creates multiple public health risks if the capacity of a population to evacuate from an event is restricted and if individuals have difficulty accessing hospitals or other essential health services. The risks may be compounded further if water delivery or wastewater treatments systems are compromised, especially if disruptions last more than a few days.

The goal of public health adaptation strategies is to minimize the negative health impacts of climate change. A summary of near-term and long-term actions from the 2009 California Climate Adaptation Strategy report are outlined in **Table 4.1** and include community education and engagement, public health workforce development, identification of co-benefits, bolstering existing functions of public health professionals, multi-sectorial partnership building, and research.

TABLE 4.1

STRATEGY	NEAR-TERM ACTIONS	LONG-TERM ACTIONS
1. Promote community resilience to climate change to reduce vulnerability	• Promote healthy, built environments • Identify and reduce health vulnerabilities • Improve food security and quality	• Promote food sustainability • Reduce heat islands • Support social and community engagement • Promote increased access to health care
2. Educate, empower and engage California residents, organizations and businesses to reduce vulnerability	• Educational outreach campaign tying into existing efforts • Specific outreach to vulnerable populations	
3. Identify and promote mitigation and adaptation strategies with public health co-benefits	• Identify and prioritize strategies with public health co-benefits	

TABLE 4.1 CONT'D

STRATEGY	NEAR-TERM ACTIONS	LONG-TERM ACTIONS
4. Establish, improve and maintain mechanisms for robust rapid surveillance of environmental conditions, climate-related illness, vulnerabilities, and adaptive capacities	• Monitor outcomes (state and local) • Develop existing environmental contaminant biomonitoring • Maintain and upgrade water accessibility information • Improve heat warning systems	• Convert to electronic surveillance systems to improve disease reporting, management and surveillance
5. Improve and sustain public health preparedness and emergency response	• Refine existing preparedness plans and conduct exercises	
6. Work in multi-sectoral partnerships (local, regional, state and federal)	• Expand training and education to build collaborative capacity	
7. Conduct applied research to support promotion and protection of human health	• Vulnerability assessments • Research collaboration • Assess local impacts on health	
8. Implement policy changes at local, regional and national levels	• Policy collaboration with stakeholders • Occupational safety standards	• Model policies and training • Public engagement
9. Identify, develop and maintain adequate funding for implementation of public health adaptation strategy	• Identify and develop funding mechanisms	• Develop funding mechanisms/ AB32 for education and research

Public health strategies for adapting to climate change (adapted from CNRA 2009)

Tribes and Cultural Resources

California indigenous communities are on the frontlines of climate change, not only in terms of ecological and social vulnerability, but also through their leadership in proactive responses to climate variability (KDNR 2016a). Climate change has already begun to impact tribal lands and waterbodies and threaten the viability of cultural resources[4] upon which California tribal communities depend. Climate change imperils tribal knowledge systems, economies, livelihoods, and cultural practices that are essential to community health and well-being as well as tribal sovereignty and self-governance (Lynn et al. 2013, Norton-Smith et al. 2016, KDNR 2016b). As Parker and Grossman (2012) remark: "Native peoples are the first to experience climate change, and the peoples who feel it the deepest, with economies and cultures that are the most vulnerable to climate-related catastrophes." Tribal communities disproportionately experience the negative impacts of climate change and are leading innovative climate-change research and adaptation initiatives at state, federal, and international levels (Cooley 2012, Levy and Patz 2015, Lynn et al. 2013, Norton-Smith et al. 2016). Here we review climate change impacts and adaptation strategies among North Coast tribal communities. Additional information on climate change impacts to California's tribal and indigenous communities is provided in a topical report of the Fourth Climate Assessment (Tribal and Indigenous Communities Summary Report).

> "Every year since the beginning of time, Karuk People have remade the world through ceremonies handed down to us by the Creator where we pray for all living things, as well as all the peoples of the earth. […] So for my people, the issues related to climate change are not just about fish, water or forests, but about something far deeper and far more meaningful. Our physical health, our spiritual health, and our cultural identity are intimately tied to the ecological integrity of the Klamath River Basin."
>
> *- Leaf Hillman, Karuk Tribe Department of Natural Resources, First Declaration of Leaf Hillman, Civ. No. 16-01079, updated 7/2018.*

Key climate-related vulnerabilities for indigenous communities in the North Coast region include food and water insecurity, reduced access to traditional foods, loss of plant, fungi, and wildlife species of cultural value, increased fire severity, extent and frequencies, and water quality threats to freshwater and marine fisheries (Bennett et al. 2014). In addition to reservation lands, Tribes are concerned with off-reservation lands and water bodies, also known as their ancestral or aboriginal territories, where they have fished, hunted, harvested, and developed relationships with specific cultural sites since time immemorial. These vulnerabilities are not an inherent feature of communities, but are the product of, and are compounded by, the history of colonialism and resource extraction which "created both the economic conditions for anthropogenic climate change and the social conditions that limit indigenous resistance and resilience capacity" (Norton-Smith et al. 2016; see also Marino 2015, Whyte 2016). The vulnerabilities of North Coast tribal communities to climate change are intensified by cumulative ecological and water quality degradation driven by mining, logging, fire suppression, and large-scale irrigated agriculture and ranching. Government policies

[4] We use the term "cultural resources" in a broad sense to refer to culturally significant species including wildlife, birds, fish, crustaceans, mollusks, plants, fungi, lichen, moss and geophytes whose populations and habitats are stewarded for food, fiber, medicine, regalia material and other cultural or spiritual purposes. Cultural resources also include water, fire, air, land and people, including the Spirit or First People.

and private sector practices that promoted resource extraction attempted to colonize tribal territories, forcibly remove or assimilate tribal communities, and marginalize or even criminalize indigenous cultures, languages, knowledges, and traditional resource management practices (e.g., Huntsinger and McCaffrey 2007, Madley 2016, Marino 2015, Norgaard 2005, Norgaard et al. 2011, Norton-Smith et al. 2016). Today many Tribes and indigenous communities are uniquely disadvantaged due to the lack of acknowledgement of their sovereign political status and the ongoing misunderstanding or misrepresentation of their culture, knowledge, and values among scientists and public agencies. As Karuk Basketweaver and Tribal Council Member Renee Stauffer commented on perceptions of traditional knowledge among resource management agencies: "We know that it's science, but they don't know. The Karuk people have survived and managed their land for thousands of years. And how long has it taken the White man to come in and destroy it? What does that say about their land and water management? They come in and they try and play God and they've ruined everything, threw everything out of balance" (Salter 2003).

Vulnerabilities of North Coast tribal communities are distinct and culturally specific, yet there are also broad areas of common concern. These include impacts to freshwater resources that provide drinking and ceremonial bathing water, as well as sustain culturally-important fish, plants, and wildlife. Other common areas of concern include impacts to coastal and marine resources, as well as range shifts in culturally significant food, fiber, medicinal, and regalia species and their habitats. Warming temperatures and altered precipitation and streamflow regimes will impact habitat for culturally significant fisheries, such as Coho salmon (*Oncorhynchus kisutch*), Chinook salmon (*O. tshawytscha*), steelhead (*O. mykiss*), Pacific lamprey eel (*Entosphenus tridentatus*), Green Sturgeon (*Acipenser medirostris*) and freshwater mussels (*Bivalvia: Unionoida*) (Butz et al. 2011, Lynn et al. 2013, Moyle et al. 2013, Sloan and Hostler 2011). According to Gregg Young, Environmental Director of the Potter Valley Tribe in Mendocino County, "With continued overharvest of ocean resources, the effects of climate change will be additive."

Wetlands, marshes, and springs that support culturally significant food (including wildfowl populations), fiber, and medicinal plants are vulnerable under projected climate scenarios (Tribal and Indigenous Communities Summary Report). Also at risk are tribal community surface and groundwater resources that supply tribal drinking water and irrigation systems. Many tribal drinking water systems are already overstressed and climate change, drought, flooding, and Harmful Algal Blooms (HABs) pose further threats to drinking water quality. The Karuk and Yurok Tribes routinely monitor for algal toxins in the Klamath river (Fetcho and Tribe 2006), while Big Valley Rancheria and Elem Indian Colony have been conducting monitoring for HABs around Clear Lake (see box on "Climate change and harmful algal blooms in Clear Lake" on page 38).[5] Climate change related degradation of water quality and quantity is a critical issue for many North Coast tribes. As a Yurok elder expressed: "Worry about the Water. Water is Life. Focus on water and the rest will follow" (Sloan and Hostler 2011).

Sea-level rise, ocean acidification, increased air and water temperatures, decreased coastal upwelling, and shifts in fog dynamics all pose threats to marine fisheries (CEC/CNRA 2018) and other coastal cultural resources such as seaweed, mussels, clams, abalone, crustaceans, invertebrates, marine mammals and birds (Sloan and Hostler 2011). Some studies warn of increased risks of shellfish poisoning among tribal cultural practitioners due to temperature shifts resulting in the spread of bacteria, viruses, and phytoplankton blooms (Lynn et al. 2013). Shifts in fog dynamics will impact coastal plant species adapted to the foggy North Coast, including species of geophytes such as the endangered western lily (*Lilium occidentale*), coastal scrub species such as hazelnut (*Corylus cornuta* ssp. *californica*),

5 See http://www.bvrancheria.com/clearlakecyanotoxins for more info.

and species such as coast redwood (*Sequoia sempervirens*) and Stika spruce that are dependent upon a regular summer fog regime. These species are of immense cultural importance to the Wiyot people and other tribes in the region (Wiyot Botanist Adam Canter pers. comm.; see also Franklin and Dyrness 1973, Holliday et al. 2012).

Humboldt Bay, or Wigi, is home to the Wiyot people. Many Wiyot sites, due to their low elevation and hyper-maritime locations, are especially vulnerable to SLR due to inundation, but also erosion. When sea levels rise, wave action is likely to erode unfortified shorelines, exposing cultural sites and threatening Wiyot artifacts, burials, and shell middens. Potentially half of the Wiyot sites on Humboldt Bay are likely to be physically damaged due to tidal inundation from sea-level rise or damaged by shoreline erosion and bluff retreat (Laird 2018). Permanent tidal inundation would prevent access and use of these sites. Shoreline erosion due to rising sea levels or extreme storm events could physically damage or even eliminate sites. The destruction or loss of access to these sites would have devastating cultural impacts on the Wiyot people. A Wiyot cultural site already experiencing erosion is the headlands at Guthrie Creek. The Tribe is an approved steward of the site and is in the process of collecting seeds from the one-leaf onion (*Allium unifolium*), an Indian potato[6] known to be eaten by the Wiyot, and will relocate the plant to stable lands on both the BLM property as well as the Wiyot's Table Bluff Reservation. The Tribe has plans to collect seed from several species of geophytes that occur at vulnerable cultural sites to ensure that their stock can be preserved for future generations of Wiyots (Adam Canter pers. comm.).

Climate impacts to culturally significant species and habitats can result in cascading social and cultural effects in tribal communities. For example, as Parker and Grossman (2012) describe, "the loss of culturally important species upon which traditional knowledge depends will make it more difficult for elders to practice and pass their knowledge to the next generation." In addition to the importance of cultural foods in revitalizing and sustaining cultural practices, lack of access to traditional foods can result in higher rates of food insecurity, diet-related illness, and mental health issues in North Coast indigenous communities (Norgaard 2005, KDNR 2016, Sowerwine 2016). In a 2015-2016 survey of 843 tribal members in the Klamath region, climate change was cited as a barrier to native food access by 68% of respondents, ranked fourth behind limited availability, degraded environment, and prohibitive rules and permits (KDNR 2016b). Like their non-tribal neighbors, Tribes may face increased exposure to extreme weather events, including droughts, floods, and wildfire, but may have less capacity to respond due to economic instability, understaffed emergency response teams, food and water insecurity, or lack of access to other resources such as home owners' insurance to help recover from disasters (Krol 2017).

Despite facing significant climate change threats, indigenous communities have been adapting to climate variability for millennia (Lynn et al. 2013, MacFarland et al. 2017, McNutt 2010, KDNR 2016a). Indigenous resource management strategies based on traditional ecological knowledge (TEK) promote and sustain resilient ecosystems, cultures, and communities (Bennett et al. 2014, Berkes et al. 2000, Williams and Hardison 2013). Numerous tribes in the North Coast region are continuing their efforts to identify climate vulnerabilities and develop strategies for adapting to climate change. These efforts also serve to strengthen community food, water, and energy systems,

[6] There are many other species of edible geophytes referred to as "Indian potatoes". Anderson and Lake (2016) mention the following genera of culturally significant edible geophytes: Allium, Brodiaea, Camassia, Chlorogalum, Calochortus, Dichelostemma, Lilium, Lomatium, Perideridia, Sanicula, and Triteleia.

improve tribal housing and infrastructure, rehabilitate ecosystems and watersheds, and revitalize culture and support tribal sovereignty (see boxes for descriptions of tribal-led climate change research, mitigation and adaptation initiatives). For example, the Klamath Basin Tribal Food Security initiative developed community-led strategies for increasing access to traditional foods and promoting the resilience of cultural agroecosystems among the Yurok, Karuk, and Klamath Tribes (Mucioki et al. 2018, Sowerwine 2016). The Karuk Tribe has been pioneering community-engaged approaches to climate vulnerability assessment, collaborative fire management, eco-cultural revitalization, and climate resilience (see "Karuk Tribe Cultural Prescribed Fire and Climate Resilience" box, below). Federal and state policy recognizes tribal sovereignty and supports tribal self-determination through government-to-government negotiation and collaboration in climate change adaptation planning and climate governance initiatives.[7] In addition, indigenous nations have been active participants in international climate policy conversations, for instance through Declarations and Statements to the United Nations Framework Convention on Climate Change (Parker and Grossman 2012) and the creation of the UNFCCC-SBSTA "Local Communities and Indigenous Peoples Platform", which aims to "facilitate stronger and more ambitious climate action by indigenous peoples and local communities"[8].

7 E.g. Executive Order B-10-11; California Energy Commission Tribal Consultation Policy, CEC-700-2017-002-D, December 2017; California Natural Resource Agency Tribal Consultation Policy, 11/20/12.

8 UNFCCC Subsidiary Body for Scientific and Technological Advice Forty-seventh session, Bonn, 6–15 November 2017, Agenda item 13. UNFCCC/SBSTA/2017/L.29. This platform encourages Parties to "consider their respective obligations on the rights of indigenous peoples and local communities" when taking action to address climate change, it emphasizes "the role of local communities and indigenous peoples in achieving the targets and goals set in the Convention" and "reaffirm(s) the need to strengthen the knowledge, technologies, practices and efforts of local communities and indigenous peoples related to addressing and responding to climate change".

KARUK TRIBE CULTURAL PRESCRIBED FIRE AND CLIMATE RESILIENCE

Karuk Tribe

The Karuk Tribe is located on the Klamath River in Northern California, where fires are an integral part of forest ecology and central component of Karuk management and culture. However, increased fire severity and frequency poses particular and unique risks to specific Karuk cultural use species on the one hand, and to broader Tribal programmatic goals and activities on the other. Taken together, climate change and settler-colonial management regimes have created landscape conditions that have the potential to transition much of Karuk Aboriginal Territory to an early seral condition with a tendency to repeatedly burn at high severity (Cocking et al. 2012, Odion et al. 2010).

Karuk people are fortunate to retain relationships with hundreds of species considered relations (Lake 2007). These foods, medicines, and fibers are embedded within cultural, social, spiritual, economic, and political systems – in short, in daily life (Lake and Long 2014, Norgaard 2014). As Lisa Hillman, the Karuk Píkyav Field Institute Program Manager, describes, "Dissecting the world into essential moving forces, we consider five elements: water, earth, air, fire and the spirits. To nurture the biodiversity of our many unique ecosystems, however, we understand that we must consider each of these elements in the everyday choices we make." Impacts to culturally significant species in the face of climate change have thus more direct impacts on Karuk people than for communities that no longer retain such intimate connections with other beings and places in the natural world. Consequently, the strength of these connections amplify the vulnerabilities Karuk people face as the climate shifts dramatically. For example, the loss of tan oak groves where families have gathered acorns for generations has a deep cultural impact that goes beyond economics.

There is increasing realization that solutions to climate change must be found in community-based models that prioritize long-term social and environmental well-being. The Karuk Tribe has taken a comprehensive approach to climate adaptation planning that considers how climate change and the associated responses of other non-Native agencies may affect cultural use species and habitats, as well as program infrastructure. In addition, they are analyzing the impact on jurisdictional recognition, tribal management authority and sovereignty. These vulnerabilities must be understood in the context of existing threats, as well as the past, present, and future management actions of Tribal and non-Tribal land managers. Not only does high severity wildfire hold the potential to negatively affect some species more than others for biological reasons, species with already compromised ecological niches that may have more difficulty in adapting will be at greater risk in the event of large scale, high severity wildfires. Furthermore, past management actions such as logging, road building, and fire suppression interact with wildfire events to influence the level of eco-cultural vulnerability, as do management actions taken during a wildfire and those that may follow in the long term. As such, the Karuk Climate Vulnerability Assessment and Climate Adaptation Plan[9] also consider how past management actions, including those taken during wildfire events, and those that may be taken in the future, may create vulnerabilities for a given species. Understanding climate-induced vulnerabilities for particular species therefore requires an interdisciplinary approach that incorporates biological and fire science with sociological understanding of human factors. Discussions of habitat zones and species profiles reflect this intersectional dimension to vulnerability.

Fortunately, in the face of the changing climate, many non-Native ecologists, fire scientists, and policy makers have turned to the indigenous knowledge and management practices of their Native colleagues with renewed interest and optimism in the hope that they may provide a much needed path towards both adaptation and reducing emissions (Martinez 2011, Raygorodetsky 2015, Vinyeta and Lynn 2013, Whyte 2013, Wildcat 2013, Williams and Hardison 2013). In the context of climate change, tribal knowledge and management principles regarding the use of fire can be utilized to reduce the likelihood of high severity wildfires and thereby protect public as well as tribal trust resources (Norgaard 2014). In particular, there is increasing recognition of the importance of indigenous burning as an ecosystem component and restoration technique.

Fire is especially important for restoring meadows and grasslands for elk, managing for food sources including tan and black oak acorns, maintaining quality basketry materials, producing smoke that can reduce water temperatures for migrating fish, and more. Karuk fire regimes generate pyrodiversity on the landscape by extending the season of burn and shortening fire return intervals. Fire can liberate nutrients (e.g. calcium, potassium, phosphorus) from organic matter and increase the production and protein quality of certain forest plants, while also providing protection from pathogens (Gregg Young, pers. comm.). The multitude of foods, materials, and other products that come from Karuk environments are in turn evidence of the profound diversity of indigenous fire regimes that are required to maintain relationships with hundreds of animal, plant, and mushroom species (Anderson and Lake 2013, Lake 2007, Lake and Long 2014).

9 See https://karuktribeclimatechangeprojects.wordpress.com/vulnerability-assessment/

For more information:

Karuk Tribe Climate Change Projects Website (https://karuktribeclimatechangeprojects.wordpress.com)

Western Klamath Restoration Partnership (https://www.wkrp.network/)

National Cohesive Wildland Fire Management Strategy (http://wildfireinthewest.blogspot.com/)

Fire Adapted Communities Learning Network (https://fireadaptednetwork.org/).

The "Endowment for Eco-Cultural Revitalization Fund" has been developed by the Karuk Tribe's Department of Natural Resources through the Humboldt Area Foundation for the purposes of funding Karuk eco-cultural revitalization initiatives. See: hafoundation.org/EcoCultural for more information and to donate in support of Karuk Eco-Cultural Revitalization.

The diversity of traditional ecological knowledge traditions and stewardship practices among tribal communities of the North Coast region hold considerable promise for adapting to climate change in California. MacFarland et al. (2017) argue that "increased awareness and appreciation" of traditional knowledge can be "a viable and important component of climate change adaptation." In addition to supporting more comprehensive climate research and policy, including tribal representatives and perspectives in climate change research and adaptation planning can help avoid the further marginalization of indigenous knowledge and cultural perspectives in resource management processes (Whyte 2016). Tribal representatives should be centrally involved in conducting climate change vulnerability assessments and adaptation planning initiatives to ensure that indigenous knowledges, values, and priorities are appropriately included in climate research and policy (Norton-Smith et al. 2016, Whyte 2016). In their 2014 "Guidelines for Considering Traditional Knowledges in Climate Change Initiatives", the Climate and Traditional Knowledges Workgroup stated: "TEK is tribally proprietary and inclusion of TEK should support and respect the sovereignty of Tribes and have safeguards through free, prior and informed consent with careful consideration of risks and opportunities" (Joe Hostler pers. comm.).

If steps are taken to include tribal communities as full partners, on their own terms and in accordance with indigenous cultural values, climate change research and adaptation planning initiatives can create opportunities for culturally appropriate jobs, workforce training, and youth education while building community capacity for resilient tribal economies and eco-cultural systems. For example, the Yurok Tribe's Carbon Forest, Community Forest and Blue Creek Salmon Sanctuary project is converting an industrial tree farm to a diverse fish and wildlife preserve and sustainable community forest, while providing "green" and culturally appropriate jobs for Yurok tribal members (see box for more information). The Blue Lake Rancheria is utilizing a range of approaches to reduce its carbon footprint, which simultaneously improves disaster preparedness and reduces energy and electricity costs for tribal members (see box for more information). More climate related education, capacity building, and training opportunities designed specifically for tribal youth are needed. Overall, more tribal community-based research and collaborative partnerships are needed to understand and address the site-specific impacts of climate change on North Coast tribal communities, including their foodways, livelihoods and economies, ecosystems and watersheds, cultural resources, health, and well-being (Cooley 2012).

YUROK TRIBE'S CARBON FOREST, COMMUNITY FOREST AND BLUE CREEK SALMON SANCTUARY

Joe Hostler

Taking advantage of an historic opportunity, Western Rivers Conservancy (WRC) and the Yurok Tribe are acquiring 47,097 acres from a timber company to establish a carbon forest, a community forest, and a salmon sanctuary along the Lower Klamath River. Yurok people have utilized the Lower Klamath River for its fisheries and cultural values since time immemorial. Returning part of this land to the Yurok will transform the landscape along 33 miles of the River from an industrial tree farm to a diverse fish and wildlife preserve and sustainable forest managed by the original stewards of the land. Central to this effort is Blue Creek, a vital cold-water tributary to the Lower Klamath River that is a lifeline for migrating salmonids and is essential to the survival of anadromous fish runs throughout the Klamath Basin.

Blue Creek flowing into the Klamath River, 16 miles upstream from its mouth. (Photo: Peter Marbach)

To establish a Sanctuary and Community Forest of this scale, WRC and the Yurok are pioneering new approaches to conservation finance. When the property is transferred to the Yurok Tribe, carbon revenues will be used for natural resource management and to provide for quality resource-based Tribal employment (i.e. "green jobs"). The overall management approach will use the best available science and applied adaptive management, guided by traditional Yurok cultural values and appropriate traditional management practices. Sustainable forestry practices will rejuvenate old-growth forests and improve the overall health and resiliency of the lands for native fish and wildlife, which will greatly improve conditions for the Yurok people who rely on the Klamath River for their cultural and economic livelihoods.

When acquisition of the Sanctuary and Community Forest are complete, it will help ensure restoration and conservation of one of the most biologically rich areas on Earth and protect and enhance vital fish and wildlife habitat and promote species recovery and resilience to resource threats such as drought and climate change. It will also reestablish Yurok homelands while promoting sustainable resource-based economic opportunities for a community whose greatest cultural, spiritual, and economic interests are healthy and resilient habitats capable of supporting robust, self-sustaining populations of native fish and wildlife.

BLUE LAKE RANCHERIA CLIMATE RESILIENCE INITIATIVES

Jana Ganion

The Blue Lake Rancheria is a federally recognized tribal government and community located in the rural, geographically isolated north coast near Blue Lake, California. Local climate impacts of concern include severe storms with heavy rains, high winds, and flooding. Landslides across major arterials are common. Drought degrades endangered species habitats and increases toxic cyanobacteria in the Mad River, which supplies drinking water for the region. Temperature increases, pest infestations, tree mortality, and unmanaged undergrowth in the region's forests contribute to large wildfires on an annual and increasingly year-round basis.

Aerial view of the Blue Lake Rancheria 500kW solar array within the Tribe's low-carbon community microgrid (Photo: Blue Lake Rancheria)

Utilizing a range of approaches – continual energy efficiency upgrades, microgrids, solar power, battery storage, and transitioning to green transportation – the Tribe is simultaneously improving disaster preparedness, reducing costs, and shrinking its carbon footprint. To date, the Tribe has reduced energy consumption by 40 percent (from a 2014 baseline) and has committed to reduce net greenhouse gas (GHG) emissions to zero by 2030. Powered by solar PV paired with battery storage, the Tribe's community microgrid alone achieves annual cost savings of $200,000 and reduces GHGs by about 195 tons of carbon dioxide. The microgrid can also disconnect from the larger electric grid and generate its own emergency power for as long as needed to support critical infrastructure and a certified American Red Cross shelter. For pairing GHG reductions with improved resilience, the microgrid was named the DistribuTECH / *PowerGrid International* distributed energy resource "2018 Project of the Year." The Tribe was selected as a U.S. "Climate Action Champions" by the White House and U.S. Department of Energy, and recognized with FEMA's "2017 Whole Community Preparedness Award."

Other illustrative Blue Lake Rancheria Climate Initiatives include:

- Community-scale and residential-scale renewable energy, including solar PV, battery storage, microgrids , and electric vehicle charging stations.
- Low-carbon transportation, including electric vehicles (EV) and EV charging stations, biodiesel manufacturing, EV public transit buses, green commuting programs.

- Smart water grid and water conservation measures.
- Tribal Utility Authority responsible for managing low-carbon, low cost resilience programs reservation-wide.
- Community-wide recycling.
- Energy efficiency improvements, including automated fixtures, high-efficiency refrigeration and HVAC, LED lighting, low-flow plumbing, upgraded insulation and windows, commercial and residential efficiency audits.

The Tribe also maintains outreach efforts to support coordination and collaboration in the low-carbon resilience sector and was appointed to the U.S. Department of Energy's Indian Country Energy and Infrastructure Working Group, California's Integrated Climate Adaptation and Resiliency Program Technical Advisory Council, and California's AB 617 Community Air Protection Program Consultation Group. Blue Lake Rancheria was the first tribal government to join the "We Are Still In" initiative to maintain the Paris Climate Agreement and the Tribe is a member of the U.S. EPA's Green Power Partnership.

For more information:

- Wood, Elisa. "Tribal Microgrid in Northern California Shows How Communities Can Lead on Climate" in Microgrid Knowledge. 4/28/2017. https://microgridknowledge.com/tribal-microgrid/
- US Climate Resilience Toolkit. "Blue Lake Rancheria Tribe Undertakes Innovative Action to Reduce the Causes of Climate Change". June 4, 2018: https://toolkit.climate.gov/case-studies/blue-lake-rancheria-tribe-undertakes-innovative-action-reduce-causes-climate-change
- "When you control your own energy, you control your future" video: https://www.youtube.com/watch?reload=9&v=6FcI4CHKh7g
- Federal Emergency Management Authority Individual and Community Preparedness Division 2017 John D. Solomon Whole Community Preparedness Award Blue Lake Rancheria, California: https://www.ready.gov/awards. Video by FEMA-ICPD, Mar.26,2018: https://www.fema.gov/medialibrary/assets/videos/161742
- California Department of Water Resources "Climate Conversations" video: https://www.youtube.com/watch?v=YcmmK1HDr7Q&feature=youtu.be

Knowledge Gaps and Looking Ahead

Improvements in the spatial resolution and accuracy of climate models will reduce uncertainty in our predictions of climate change impacts. For the North Coast region, improved predictions of near-coast weather and fog trends will be particularly important for planners and resources managers along the coast. Improved fire models that account for the dynamic interplay between climate change, tree mortality, fire intensity and frequency, and vegetation responses are also needed by planners and resource managers throughout the region. Better understanding, modeling, and prediction of fish and wildlife responses to changing patterns in landscape water availability, streamflow patterns, and water temperatures would help to inform conservation strategies. Finally, there is a need to advance sea-level rise predictions for the region that take into account local variation in vertical land movement, regional sea-level rise trends, and potential changes in the direction and intensity of waves. The planned extension of the Coastal Storm Modeling System[10] (CoSMoS) to the North Coast will be helpful in this regard.

While models are a valuable tool for decision-making, the importance of building capacity within communities to engage in climate adaptation decisions cannot be overstated. Creating opportunities for robust stakeholder participation in planning processes and development decisions helps to raise awareness of climate hazards, builds a common understanding of key vulnerabilities, and allows local perceptions and preferences to guide the selection of adaptation strategies. Climate change is only one of many issues that threaten the health and prosperity of communities of the North Coast, but as described above, will affect nearly all aspects of life in the region, including ecosystems, the built environment, and public health. Therefore, greater effort should be invested in integrating climate change into existing planning and decision-making processes that traditionally have excluded climate change considerations. The more climate change is taken into account in long-term decisions, especially those regarding infrastructure and development projects, the more communities will be prepared to cope with climate change impacts in the future.

The extensive and largely intact ecosystems of the North Coast Region provide unique opportunities for natural infrastructure approaches to climate adaptation. These include watershed restoration activities to attenuate floods and improve water quality and the use of salt marshes and other coastal habitats to buffer sea level rise and facilitate the planned retreat of infrastructure assets from vulnerable areas. As an important contributor to statewide water supplies, carbon sequestration, and biodiversity, an economic valuation of the region's "natural capital" could also help direct State and Federal resources to the North Coast to improve natural resource management and advance adaptation efforts.

Freshwater and terrestrial ecosystems will respond in complex ways to a changing climate and predictions of future environmental conditions will depend on the specific trajectory of regional climate and wildfire patterns that cannot be predicted with accuracy. An improved environmental monitoring network would be helpful for tracking regional trends in ecosystem conditions (including water, temperature, vegetation, and animal communities), assessing the status of vulnerable species, and allowing for early detection of pests, disease, and invasive species. The identification and protection of watersheds in the region that may serve as climate refugia for sensitive plant and animal species will be an essential element of a long-term ecosystem management and conservation strategies. Research to guide the selection of these locations, and to understand the underlying physical processes that sustain climate refugia, is needed. Improved environmental surveillance is also needed to assess public health risks, especially for vulnerable

[10] https://northcoastresourcepartnership.org

communities. This would involve improved real-time monitoring of air quality, water quality, flood, wildfire, and heat risks, and reporting information in widely accessible electronic information systems.

Different sectors will have differing responses to climate related stressors and disturbances, but actions to ameliorate impacts to any one sector may confer benefits or costs to others (Cooley 2012). Therefore, careful attention must be given to such cross-sector linkages to avoid actions that produce unintended adverse consequences and to identify strategies that produce co-benefits, where possible. For example, natural infrastructure approaches to shoreline protection in the coastal zone can reduce flood risk while creating benefits for estuarine ecosystem health and wildlife. Prescribed wildfire programs reduce public health and safety risks, build community-awareness and understanding of wildfire processes, and improve forest health. Improved irrigation, fertilizer, and soil management techniques in agriculture can save water, reduce their carbon footprint, and in some cases, enhance wildlife habitat. Programs that promote the use of traditional ecological knowledge in managing natural resources can help to reduce fire risk and improve ecosystem health, while preserving the traditions of tribal communities. Additional research that explores cross-sector linkages and quantifies the costs and benefits of alternative actions would be valuable.

By breaking down traditional sectors, climate change also creates opportunities for new partnerships among local and regional governments, natural resource and health agencies, private industry, tribes, and NGOs. One such effort is the North Coast Resource Partnership (NCRP)[11], a collaboration among Northern California Tribes, local, state, and federal agencies, utility service providers, NGOs, private landowners, and other stakeholders that has existed since 2004. The NCRP collects data and performs analyses to inform regional and local planning with the intention of implementing projects that enhance ecosystems and human communities. The NCRP is a member of Alliance of Regional Collaborative for Climate Adaptation (ARCA) and actively conducts research and takes action on climate change adaptation across multiple sectors. Recent NCRP-funded projects address regional climate change impacts (Micheli et al. 2018), adaptation strategies (Reza Environmental and Tillman 2018), and strategies for reducing GHG emissions in the region (Redwood Coast Energy Authority and Woods Biological Services 2018). Such partnerships are not only needed for addressing climate change challenges, but will help the region be more competitive for State and Federal funding to support needed climate vulnerability assessments and adaption projects in the future.

Overall, the North Coast region has taken significant steps towards understanding what climate change means for its communities, ecosystems, and working lands and the strategies that are needed to limit social and environmental impacts. By continuing to enhance the region's collective scientific, economic, and social capacity in addressing climate change, there is little doubt that North Coast communities will find novel ways to adapt, while preserving region's unique character, natural resources, and cultures.

11 https://northcoastresourcepartnership.org

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