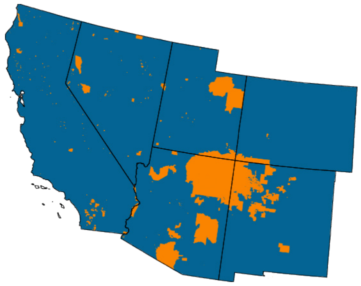
Fifth National Climate Assessment: Chapter 28

Southwest



Chapter 28. Southwest

Authors and Contributors

Federal Coordinating Lead Author

Emile H. Elias, USDA Agricultural Research Service, Southwest Climate Hub

Chapter Lead Author

Dave D. White, Arizona State University

Agency Chapter Lead Author

Kathryn A. Thomas, US Geological Survey, Southwest Biological Science Center

Chapter Authors

Cristina E. Bradatan, US Census Bureau, International Programs Center

Mark W. Brunson, Utah State University, Department of Environment and Society

Ann Marie Chischilly, Northern Arizona University, Institute for Tribal Environmental Professionals

Carolyn A.F. Enquist, US Geological Survey, Southwest Climate Adaptation Science Center

Leah R. Fisher, California Department of Transportation

Halley E. Froehlich, University of California, Santa Barbara

Elizabeth A. Koebele, University of Nevada, Reno

Michael Méndez, University of California, Irvine

Steven M. Ostoja, USDA Agricultural Research Service, California Climate Hub

Caitriana Steele, New Mexico State University

Jennifer K. Vanos, Arizona State University

Technical Contributors

Grace Di Cecco, Eagle Rock Analytics

Owen M. Doherty, Eagle Rock Analytics

Victoria L. Ford, Eagle Rock Analytics

Gerald C. Nelson, University of Illinois at Urbana–Champaign

Ashley Quay, unaffiliated

Scott Stephens, University of California, Berkeley, Department of Environmental Science, Policy, and Management

Review Editor

Olivia T. Yip, San Jose State University

Cover Art

Diya P.

Recommended Citation

White, D.D., E.H. Elias, K.A. Thomas, C.E. Bradatan, M.W. Brunson, A.M. Chischilly, C.A.F. Enquist, L.R. Fisher, H.E. Froehlich, E.A. Koebele, M. Méndez, S.M. Ostoja, C. Steele, and J.K. Vanos, 2023: Ch. 28. Southwest. In: *Fifth National Climate Assessment*. Crimmins, A.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, B.C. Stewart, and T.K. Maycock, Eds. U.S. Global Change Research Program, Washington, DC, USA. https://doi.org/10.7930/NCA5.2023.CH28

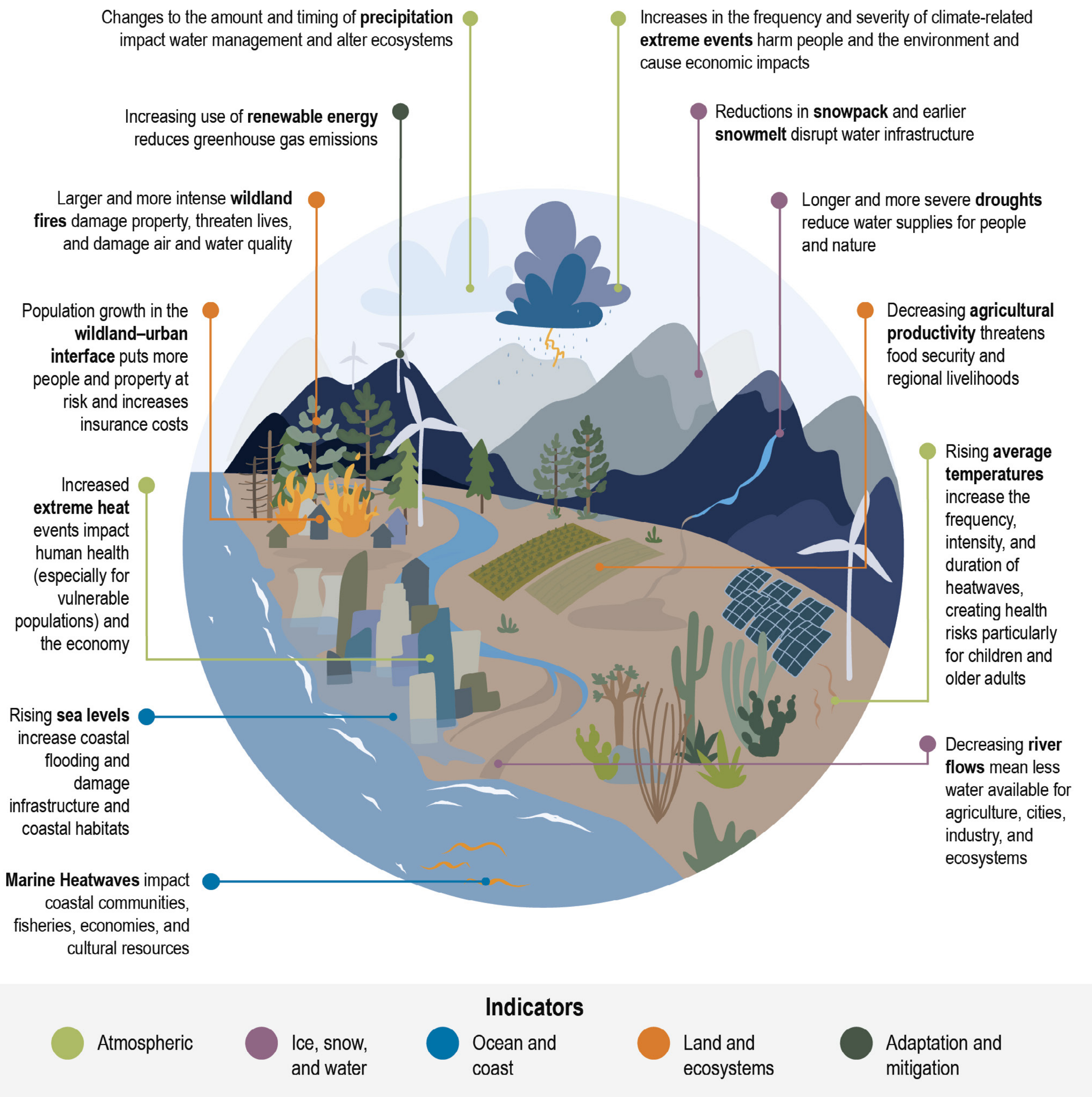
Table of Contents

Introduction

The Southwest encompasses diverse natural ecosystems, vibrant cultures, and productive economies. This vast region spans nearly 700,000 square miles, or 18% of the US land area.[1] The Southwest is home to more than 60 million people and is among the fastest growing and most economically productive areas of the country. Southwest ecosystems provide society with food, energy, and water; regulate climate; protect against disasters and disturbances; and offer the settings and inspiration for meaningful social, cultural, recreational, and spiritual experiences (Figure 8.17).

Climate change is negatively impacting human health and well-being (KM 15.1), cultural heritage, property, built infrastructure, economic prosperity, natural capital, and ecosystem services across the Southwest (Figure 28.1). Impacts include rising air temperatures[2] and sea surface temperatures, both attributable in part to human activities;[3] changes to the timing, form, and amount of precipitation;[4,5,6] sea level rise and associated flooding events;[7] increases in extreme heat events;[8] summertime heat stress[9,10] and heat-related mortality;[11] surface and groundwater reductions;[12,13,14,15,16] increased wildfire risks;[17,18,19,20,21] and changes to ocean chemistry. These impacts pose heightened risks to overburdened and frontline communities and to Indigenous Peoples (KMs 4.2, 15.2, 16.1).

Climate Change Indicators, Impacts, and Responses in the Southwest



Indicators highlight important climate impacts and adaptation and mitigation efforts.

Figure 28.1. Indicators track the impacts of climate change on the atmosphere; ice, snow, and water; ocean and coast; and land and ecosystems, as well as adaptation and mitigation efforts. Monitoring these indicators helps us understand how impacts are experienced and how to adapt to risks. See Appendix 4 for more Indicators. Figure credit: Arizona State University. See figure metadata for additional contributors.

Southwest ecosystems transition from deserts and grasslands in hotter and lower elevations to forests and alpine meadows in cooler, higher elevations. The region supports important terrestrial and marine biodiversity and ecosystems, including the Sonoran Desert, the Sierra Nevada, and the Pacific Coast. The southern deserts commonly see temperatures between 105° and 115°F, and Phoenix has the hottest climate of all major US cities. The California coast stretches 3,400 miles (5,500 km), and its coastal wetlands provide critical habitat for fish and wildlife, protect water quality, and buffer against storms and floods.

The region is heavily urbanized, with 9 out of 10 people living in cities such as Albuquerque, Denver, Las Vegas, Los Angeles, Phoenix, Salt Lake City, and San Francisco. The region is also a major hub for software innovation, information technology, and semiconductor manufacturing. California's economy alone contributed more than $3.21 trillion (in 2022 dollars) to the US GDP in 2021, about 12% of the total US economy.[22] The region also encompasses expansive rural areas with livelihoods centered on ranching, mining, agriculture, and tourism.

Indigenous Peoples and Tribal lands are essential to the social, cultural, and geographic identity of the region. The Southwest is home to 182 Federally Recognized Tribes,[23] as well as numerous state-recognized Tribes and Tribes seeking state or federal recognition. California has the largest number of Federally Recognized Tribes (109) and the largest Indigenous population of any state.[23] Arizona, New Mexico, Colorado, and Utah are home to seven of the most populous Tribes, ranging from 10,000 to more than 300,000 members. Nine Tribes in the Southwest are considered "large land-holding Tribes," five of which are among the ten largest reservations in the US, ranging in size from 600,000 to 16 million acres. The largest US federal Indian reservation—the 16-million-acre Navajo Nation Reservation—occupies portions of Arizona, New Mexico, and Utah.

The Federal Government manages nearly half of the total land area of the region through national parks, forests, fish and wildlife reserves, military installations, and public lands.[24] In Nevada, the Federal Government is responsible for managing more than 80% of the total acreage of the state.[24] Thus, the Federal Government is central to adaptation and mitigation in the Southwest.

Over the past five years, climate change impacts in the Southwest have become increasingly apparent and widespread.[25] At the same time, understanding and modeling of how these impacts affect specific sectors and processes have improved. For instance, advances have been made in understanding and modeling of water,[26,27,28] food and agriculture,[29] wildfire,[19] invasive species, biodiversity loss (KM 8.2), ecosystem transformations, human health,[30] and human migration across the Southwest.[31,32] Furthermore, research has advanced understanding and modeling of interdependencies, feedbacks, and cascading risks for interconnected systems (KM 18.1) such as the food–energy–water nexus (KM 18.3).[33,34]

To address these climate change impacts, governments, nongovernmental organizations, and private enterprises are increasingly responding with planning and actions to reduce current and future risks and increase adaptive capacity. Adaptation efforts that are effective, feasible, and just—including nature-based solutions such as green infrastructure for flood mitigation—have been shown to reduce climate risk, increase resilience, and provide co-benefits to related societal goals (KM 8.3).[35] There is an awareness of new approaches to equity and environmental justice for frontline communities, as well as Indigenous Peoples (KM 16.2) across the Southwest. These approaches recognize, protect, and apply diverse knowledge systems, including Indigenous Knowledges (KM 16.3). Social science has also improved our understanding of inclusive, participatory, and collaborative decision-making to solve problems in this region and beyond.[36,37,38]

While this chapter focuses on climate impacts, risks, and adaptation actions in the Southwest, it also recognizes efforts underway to mitigate greenhouse gas emissions (Figure 32.20) throughout the region at multiple scales. California, Colorado, and New Mexico are members of the US Climate Alliance, committed to reducing net greenhouse gas (GHG) emissions in line with the Paris Agreement (KM 32.5). California has committed to carbon neutrality by 2045[39,40] and released a detailed plan with targets to achieve this goal,[41] as well as augmenting funding across sectors.[42] Both Colorado and New Mexico have statewide greenhouse gas reduction goals.[43,44] At the local level, dozens of cities in all Southwest states are committed to emissions reductions in line with the Paris Agreement through the bipartisan Climate Mayors network (KM 32.5). For example, the Phoenix Climate Action Plan states that the city is on track to meet its goal of 50% reduction in GHG emissions (below its 2018 baseline) by 2030 and is committed to carbon neutrality by 2050.

Key Message 28.1

Drought and Increasing Aridity Threaten Water Resources

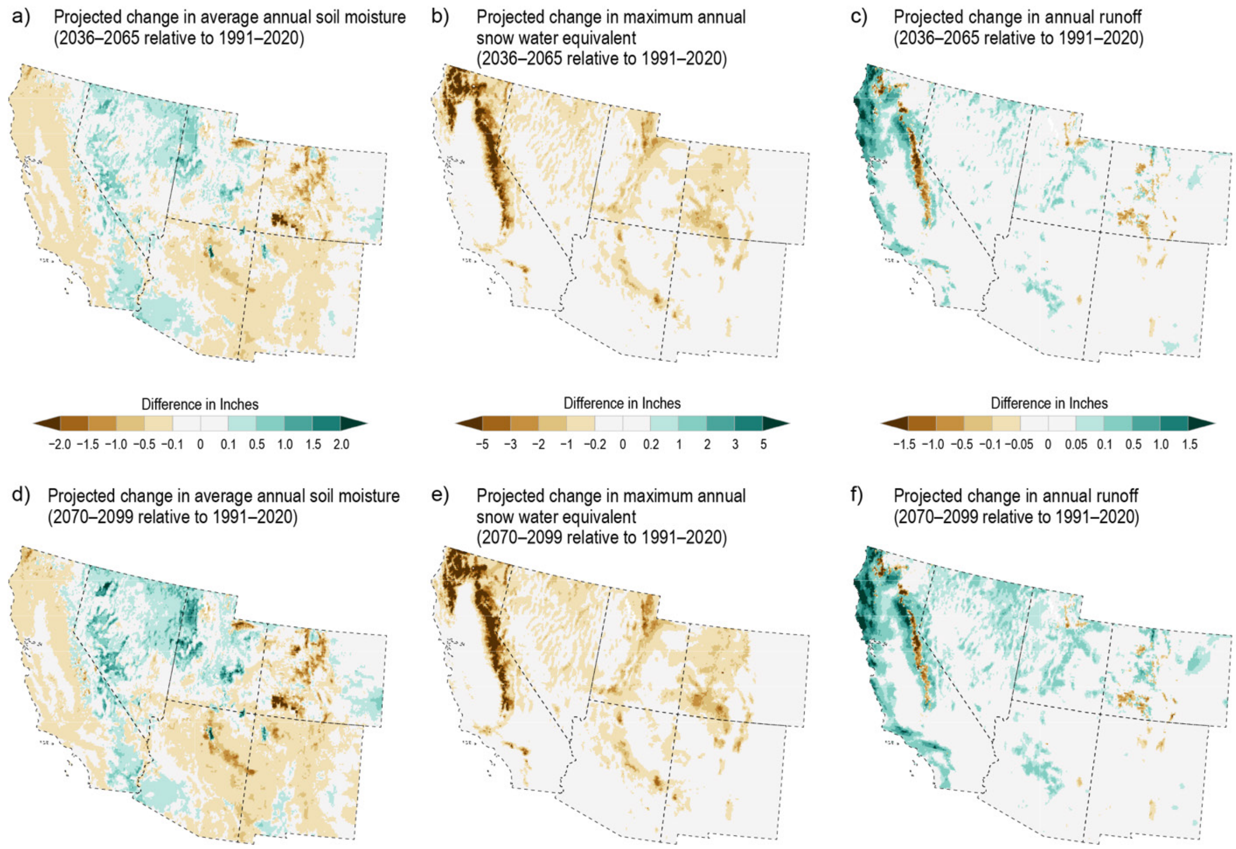
Climate change has reduced surface water and groundwater availability for people and nature in the Southwest (*very high confidence*), and there are inequities in how these impacts are experienced (*high confidence*). Higher temperatures have intensified drought and will lead to a more arid future (*very likely*, *high confidence*); without adaptation, these changes will exacerbate existing water supply–demand imbalances (*likely*, *high confidence*). At the same time, the region is experiencing more intense precipitation events, including atmospheric rivers, which contribute to increased flooding (*high confidence*). Flexible and adaptive approaches to water management have the potential to mitigate the impacts of these changes on people, the environment, and the economy (*medium confidence*).

Drought and Aridification

The Southwest region is historically arid and marked by episodes of intense drought and precipitation (KM 4.1).[45,46] Climate change is exacerbating these conditions, as increasing temperatures are leading to hotter extreme heat events, drier soils, greater atmospheric evaporative demand, and reduced flows in major river basins such as the Colorado and Rio Grande.[14,47,48,49,50] For example, between 1913 and 2017, annual average discharge from the Colorado River decreased by 9.3% for each degree Celsius of warming (Box 28.1).[49] Additionally, since 2000 the Southwest has experienced an exceptional "megadrought"—defined as an episode of intense aridity that persists for multiple decades—that is recognized as the driest 22-year period in 1,200 years.[51]

Mountain snowpack is one of the most important sources of water in the Southwest, serving as a natural reservoir to supply water to drier, lower elevations for irrigated agricultural, municipal and industrial uses, and ecosystems (KM 4.1). Observed declines in western snowpack over the last century have been predominantly driven by warming trends,[4] leading to smaller snowpack volumes, higher-elevation snow lines, and earlier snowmelt (KM 3.4).[6,52] These processes are exacerbated by the deposition of dust and other light-absorbing particles on snowpack, which accelerates snowmelt.[53] The resulting decrease in snow cover also reduces the albedo, or reflectivity, of the land surface, resulting in a positive feedback cycle that further increases solar radiation absorption, warming, and snowmelt.[49,54,55] These changing snowpack dynamics are expected to have different influences on the timing and volume of snowmelt-driven streamflow in different basins,[56] potentially disrupting the ability of existing water infrastructure, including hydropower, to meet the region's needs[5,49] and altering ecosystem dynamics. Persistent low-snow years are projected to occur in the next half century if climate change continues unabated (Figure 28.2).[5]

Projected Changes in Soil Moisture, Snow Water Equivalent, and Runoff



Climate change is projected to reduce snow water equivalent and alter trends in soil moisture and annual runoff.

Figure 28.2. These maps show projected average mid-21st-century (2036–2065; top row) and late-21st-century (2070–2099; bottom row) differences in annual soil moisture, snow water equivalent (the amount of water contained within the snowpack), and runoff over the Southwest region relative to the baseline period, 1991–2020. The data in these maps come from a land-surface hydrological model that simulates different parts of the water and energy balance. The model takes temperature and precipitation data from an ensemble of downscaled Coupled Model Intercomparison Project, Phase 5 (CMIP5) global climate models using an intermediate scenario (RCP4.5)[57] to create future projections of soil moisture, snow water equivalent, and runoff.[58] Warming temperatures and precipitation variability are expected to reduce snow water equivalent and alter trends in soil moisture and annual runoff (KM 4.1). The historical record shows that the climatology of 1991–2020 was substantially warmer than the climatology of preceding 30-year periods. Thus, the areas of projected lower soil moisture, snow water equivalent, and runoff in this figure, especially at higher elevations, present marked deficits in comparison to 30-year periods in the 20th century. There are also areas of projected increases in soil moisture and runoff. Some CMIP5 global climate models project increased precipitation over parts of the Southwest, and when these are included in calculating average soil moisture or runoff, the result indicates wetter conditions in some locations, predominantly in Nevada, Utah, southwest Arizona, and southeast California. For more detail on variability, Figures 4.5, 4.6, and 4.7 show data from the same source that illustrate the wet to dry range of projections for the mid-21st century. Figure credit: New Mexico State University; Arizona State University; University of Nevada, Reno; NOAA NCEI; and CISESS NC.

In addition to extended periods of record-low precipitation, higher temperatures driven by climate change have increased evapotranspiration and reduced soil moisture, which can reduce the volume of runoff produced from a given amount of precipitation.[16,47,50,59] These trends have negatively impacted natural resource management and agricultural production (KM 11.1) by increasing stress on vegetation.[60] Coupled with increases in demand and subsequent water withdrawals, reduced streamflow has caused many of the region's lakes and reservoirs, such as the Great Salt Lake, to reach historically low water levels.[61] Furthermore, greater variability in streamflow threatens the region's ability to consistently produce and use hydropower, impacting a typically reliable and low-carbon source of energy.[62]

Climate warming will also reduce groundwater recharge from rainfall, snowmelt, and runoff in some areas, thereby reducing groundwater storage.[63,64] These effects are exacerbated by groundwater pumping to satisfy the needs of agricultural irrigation,[65,66] which is the biggest consumer of fresh water in the region. The Central Valley aquifer of California is one of the most stressed aquifers in the world; during the 2012–2016 drought, about two-thirds of the valley's surface water deficit was due to groundwater pumping, which caused land subsidence (the gradual sinking of land) in some areas[67] and declines in groundwater quality.

Flooding

Despite the region's increasing aridity, flooding from extreme precipitation events (KM 3.5) and snowmelt conditions (KM 4.1) also poses a threat to life and property, as well as to freshwater ecosystems.[68,69] Due to climate change, snowmelt-driven flooding is expected to occur earlier in the year due to earlier runoff.[70] Moreover, atmospheric rivers, which have driven much of historical flooding in the region, are expected to intensify under a warming climate.[71,72] Flooding from sea level rise may also threaten water infrastructure and supplies in areas such as the Sacramento–San Joaquin Bay Delta region.[73,74]

Disproportionate Impacts

Critically, the impacts of these climate-driven changes are experienced disproportionately by certain communities in the region, including Indigenous communities (KM 16.1). A lack of clean water and sanitation services in Indigenous communities came to national light in 2020 due to COVID-19, which spread 3.5 times faster among Indigenous than non-Indigenous communities in the initial stage of the pandemic,[75] due in part to the lack of access to potable water in some Indigenous communities. A major impediment to water access is the cost of water infrastructure, which averages $600 per acre-foot of water for non-Indigenous families with piped delivery, compared to $43,000 per acre-foot of water for Navajo families relying on hauled water (no dollar year available).[76,77] Furthermore, many Tribes in the region continue to lack access to water because their water rights have not been adjudicated through settlements or other processes, which could further exacerbate water shortages for other users.[78]

Other examples of overburdened communities experiencing disproportionate water-related impacts of climate change include certain Black communities, which face disproportionately higher flood risk in Los Angeles,[79] and Hispanic and low-wealth communities, which receive lower-quality drinking water[80] and may be systematically excluded from water management processes (KM 4.3).[81]

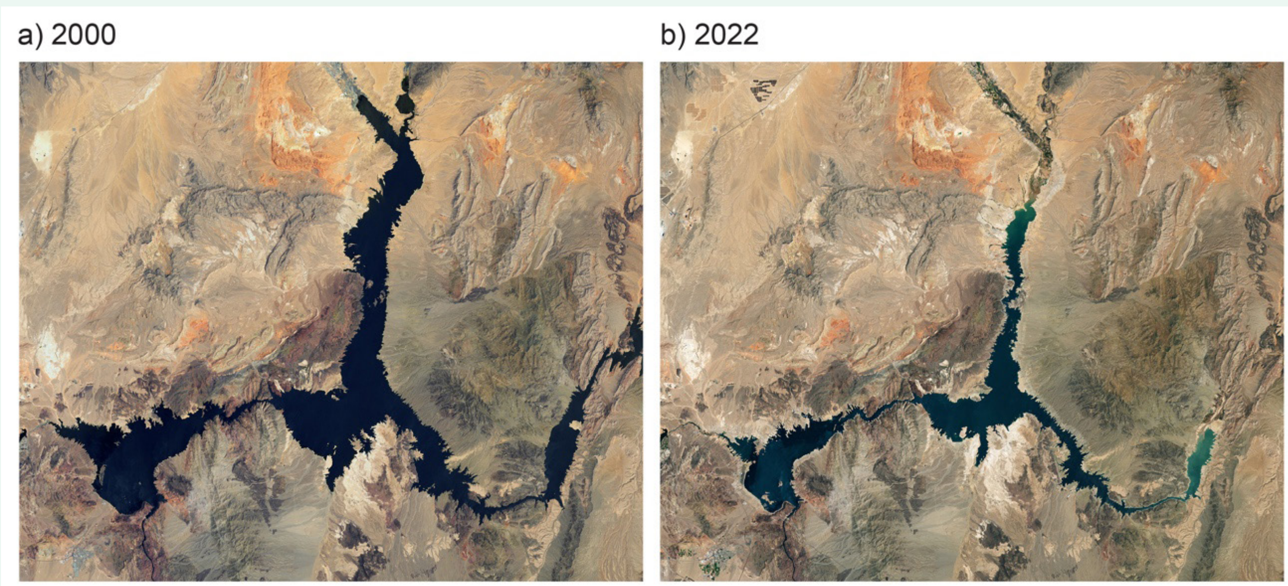
Adaptation Pathways

In response to these interrelated climate challenges, people across the Southwest have implemented adaptive water governance and management approaches. Examples include California's Sustainable Groundwater Management Act[82] and various conservation and drought response measures in the Colorado River basin,[37,38,83] which incentivize collaboration among diverse participants to develop innovative solutions (KM 12.4). Transitions toward more sustainable water management under climate change also include innovative infrastructure (e.g., enhanced aquifer storage, recharge, and recovery) and institutional practices (e.g., integrative land and water management practices, changes in rate structures, water sharing agreements, and reservoir operations).[84,85,86,87] Social science studies in Southwest cities such as Denver, Phoenix, and Las Vegas indicate widespread support for innovative management strategies for urban water sustainability[88] and opportunities for targeted educational interventions for demand management strategies based on residents' attitudes toward climate change.[89] The extent to which these adaptation actions mitigate changes in water availability depends on interacting climate and social dynamics (KM 3.4).

Box 28.1. First Water Shortage Declaration on the Colorado River

In response to more than 22 years of historic drought exacerbated by climate change and a growing imbalance between water supply and demand in the Southwest, the US Bureau of Reclamation declared the first-ever water shortage on the Colorado River in August 2021 (Figure 4.18).[90] The decision came after the agency projected that the water level in Lake Mead, the Nation's largest reservoir, would fall to 1,066 feet above sea level, or just 36% of capacity, by the end of 2021, the lowest level since the reservoir was initially filled in the 1930s (Figure 28.3). In addition to impacting water supply reliability for all users, low reservoir levels could disrupt hydropower generation, which provides electricity to several communities in the region. The initial round of water supply cuts implemented under the declaration, following previously negotiated policies, affected Arizona, Nevada, and Mexico, with Arizona farmers taking the biggest cuts. Since then, deeper and more widespread cuts, as well as calls for additional conservation measures, have been made and are expected to expand as climate change impacts continue. In response, the federal governments of the United States and Mexico, the seven US Colorado River basin states, and Indigenous Peoples are developing a range of adaptation pathways and solutions to enhance long-standing collaboration on the Colorado River (KM 16.3), including modeling the impact of more extreme climate change scenarios on water resources in the basin. Multisector conservation and demand management is seen by many as a major solution. Farms can reduce agricultural consumption by increasing water-use efficiency using technologies such as drip irrigation and alternative crop choice. Urban and industrial water conservation, recycling, and reuse improvements could support "water-smart" and economically productive industries in the Southwest. Through a partnership with Mexico on coastal water desalination, the region could free up Colorado River water for the United States while providing Mexico with a secure new supply.[91] Desalination proposals, however, have raised concerns about carbon-intensive energy demands, cost, brine management, and inequitable impacts on Mexico, including environmental impacts from brine disposal. Innovative, decentralized water treatment facilities could directly benefit communities in both countries, including those on Tribal lands.

Satellite Images of Lake Mead



Lake Mead water levels have declined, with potential water supply implications for millions of people.

Figure 28.3. Lake Mead, the largest reservoir in the US, supplies water to tens of millions of people across the Southwest; irrigates millions of acres of agricultural land; supports biodiversity, cultural heritage, ecosystems, and ecosystem services; and provides recreational opportunities. From 2000 (**a**) to 2022 (**b**), the water levels in Lake Mead declined from 98% to just 27% of its capacity, as shown in these satellite images. Satellite images: NASA Earth Observatory.

Key Message 28.2

Adaptation Efforts Increase to Address Accelerating Impacts to the Region's Coast and Ocean

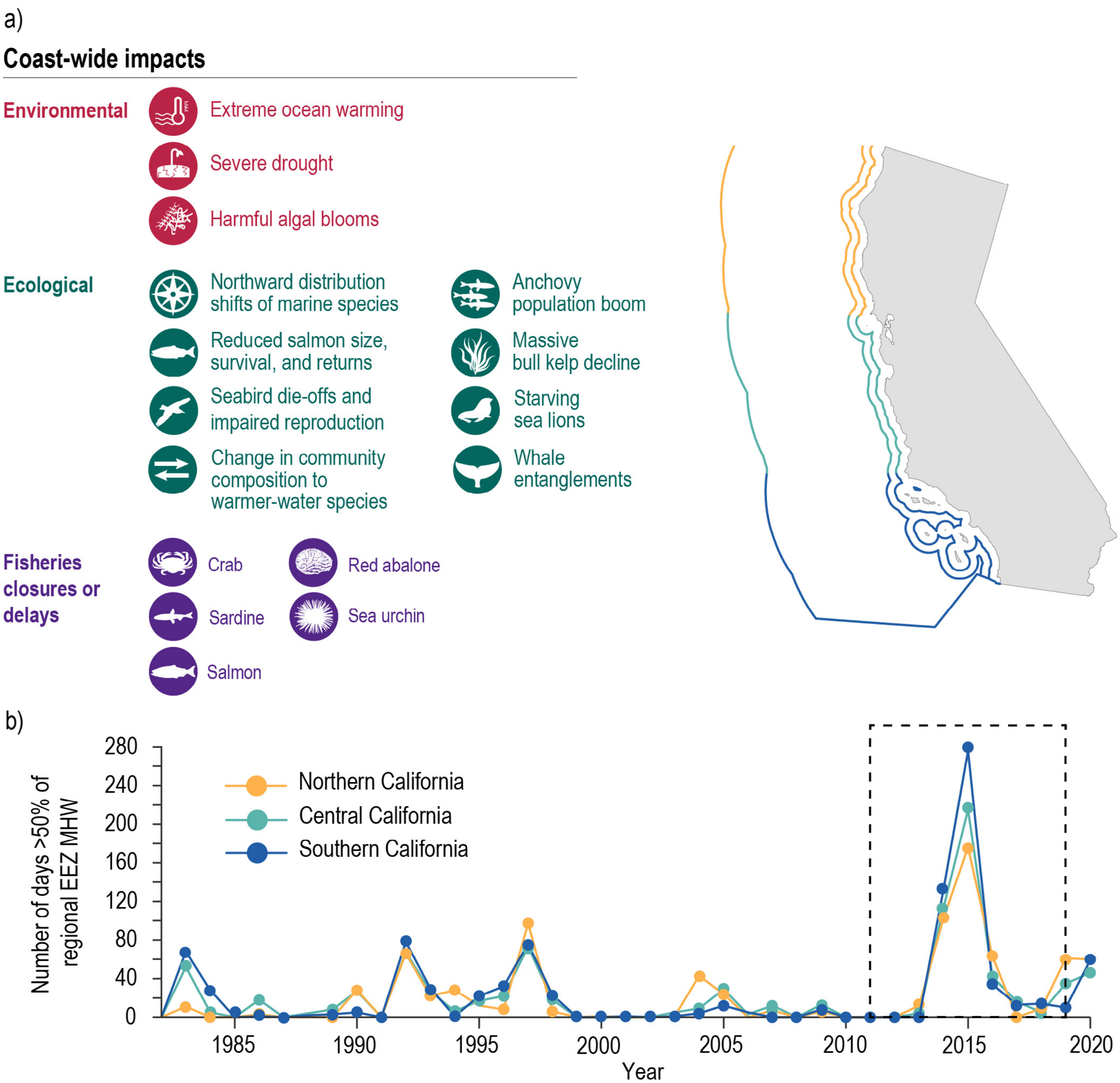
Large-scale marine heatwaves and harmful algal blooms have caused profound and cascading impacts on marine coastal ecosystems and economies (*high confidence*). Without implementation of adaptation or emissions-reductions measures, human-caused warming will drive more frequent and longer marine heatwaves (*very likely*, *very high* confidence), amplifying negative coastal effects (*medium confidence*). Sea level rise, along with associated impacts such as flooding and saltwater intrusion, will have severe and disproportionate effects on infrastructure, communities, and natural resources (*likely*, *very high confidence*). The California State Government has applied climate science to planning and decision-making for sea level rise, and multiple regions are moving toward climate-informed and adaptive strategies for fisheries (*high confidence*). However, climate planning and adaptation solutions for aquaculture are less clear (*high confidence*).

The coastal region of the Southwest encompasses approximately 3,400 miles of coastline and nearly 70% of the state's 39.4 million people. California's 19 coastal counties employ more than 12 million people[92] and in 2012 accounted for 80% of the state's GDP ($57.25 billion in 2022 dollars).[93] Furthermore, California is showing leadership through adaptation actions nationally.

Ocean Extremes and Adaptation

California coastal sea surface temperature has increased an average of 0.4°–0.6°F per decade since the 1970s[94] and is projected to increase into the future under climate change (Ch. 2).[95,96] Human-caused warming also contributes to marine heatwaves (MHWs; Figure 28.4), or incidences of exceptionally warm ocean temperatures, which have already had significant impacts on human and natural systems (Box 10.1).[97,98,99,100] The change in average cumulative intensification of MHWs for the entire US coast is presented in Figure A4.11. As the ocean warms, including in California coastal waters, MHWs increasingly exceed thermal limits of ecosystems, amplifying impacts[99] including shifts in marine species composition,[101] lower abundance and nutritional quality of important small prey fishes,[102,103] and a potential influence on mass seabird mortalities and reproduction.[104,105] Similarly, Tribal/Indigenous Traditional Knowledge demonstrates significant declines in five coastal species of cultural significance for the Tolowa Dee-ni' Nation, the Cher-Ae Heights Indian Community of the Trinidad Rancheria, the Wiyot Tribe, and the InterTribal Sinkyone Wilderness Council, a Tribal consortium of ten Tribal Nations.[106] Such ecological changes disproportionately impact coastal communities and economies (KM 9.3),[107,108,109] including cultural resources for Indigenous Peoples (KM 15.2).[106,110] The 2014–2016 Northeast Pacific marine heatwave was followed by others in 2018[111]and 2019–2020.[112] These MHWs can coincide with and contribute to other climate-related extremes such as drought[100] and harmful algal blooms (HABs).[113]

California Marine Heatwaves



Pacific marine heatwaves have had coast-wide impacts on ecosystems and fisheries.

Figure 28.4. The 2014–2016 Pacific marine heatwave (MHW) was unusually long and resulted in a variety of impacts for the southwest California coast (**a**). This MHW was followed by less extensive events in 2018 and 2019–2020 (**b**). While impacts like this can be expected to continue, they demonstrate the need and potential for adaptive management and mitigation through an integrated ecosystem approach to managing marine habitats and fisheries. EEZ refers to exclusive economic zone. Figure credit: University of California, Santa Barbara; California Department of Transportation; NOAA NCEI; and CISESS NC.

Commercial and recreational wild fisheries, as well as aquaculture (aquatic farming), will continue to be negatively affected by MHWs and HABs,[107] resulting in severe economic ramifications.[113,114,115,116] Extreme ocean warming events also have compound effects: an MHW contributed to the loss of more than 90% of Northern

California's bull kelp, a foundational species for the ocean ecosystem, resulting in large economic losses in fisheries (Focus on Blue Carbon),[117,118] including the red abalone, a species now listed as critically endangered by the International Union for Conservation of Nature. Further, extreme event–related delays and closures disproportionately impacted smaller-scale fishing operations.[119]

The widespread impacts of MHWs and HABs underscore the need for effective adaptive approaches to fisheries management. While fishers in California are coping with MHWs by fishing in different areas or for different species,[108] it will be challenging to manage fisheries in the long term under extreme warming events.[115] Marine protected areas (MPAs), which are considered a management strategy for climate-driven ocean changes, may not buffer widespread effects of MHWs on species in southern California kelp forests.[120] Adopting an ecosystem approach that considers multiple management options instead of one species in isolation[121,122] appears to improve management under climate change.[123] Applying a more coordinated disaster risk management approach to MHWs and extreme HAB events appears to correspond to better adaptive fisheries management, emphasizing the need for improving coordination and consistency across governing bodies, communities, and fishers on the frontlines (KM 10.3).[124,125]

Human-caused ocean warming coincides with increasing ocean acidification (OA) and declining oxygen levels (hypoxia) of the deeper, more nutrient-rich upwelled coastal waters. Under a very high scenario (RCP8.5), sardines, a commercially and ecologically important species, are predicted to move poleward, resulting in substantial shifts in catch.[109,126] Under the same scenario, increased acidity due to the ocean's chemical response to absorption of carbon dioxide is projected to increase the mortality of calcifying invertebrates (such as oysters and other bivalves), which are important to aquaculture and the food web, and result in a loss of food sources for some fishes and invertebrates.[127]

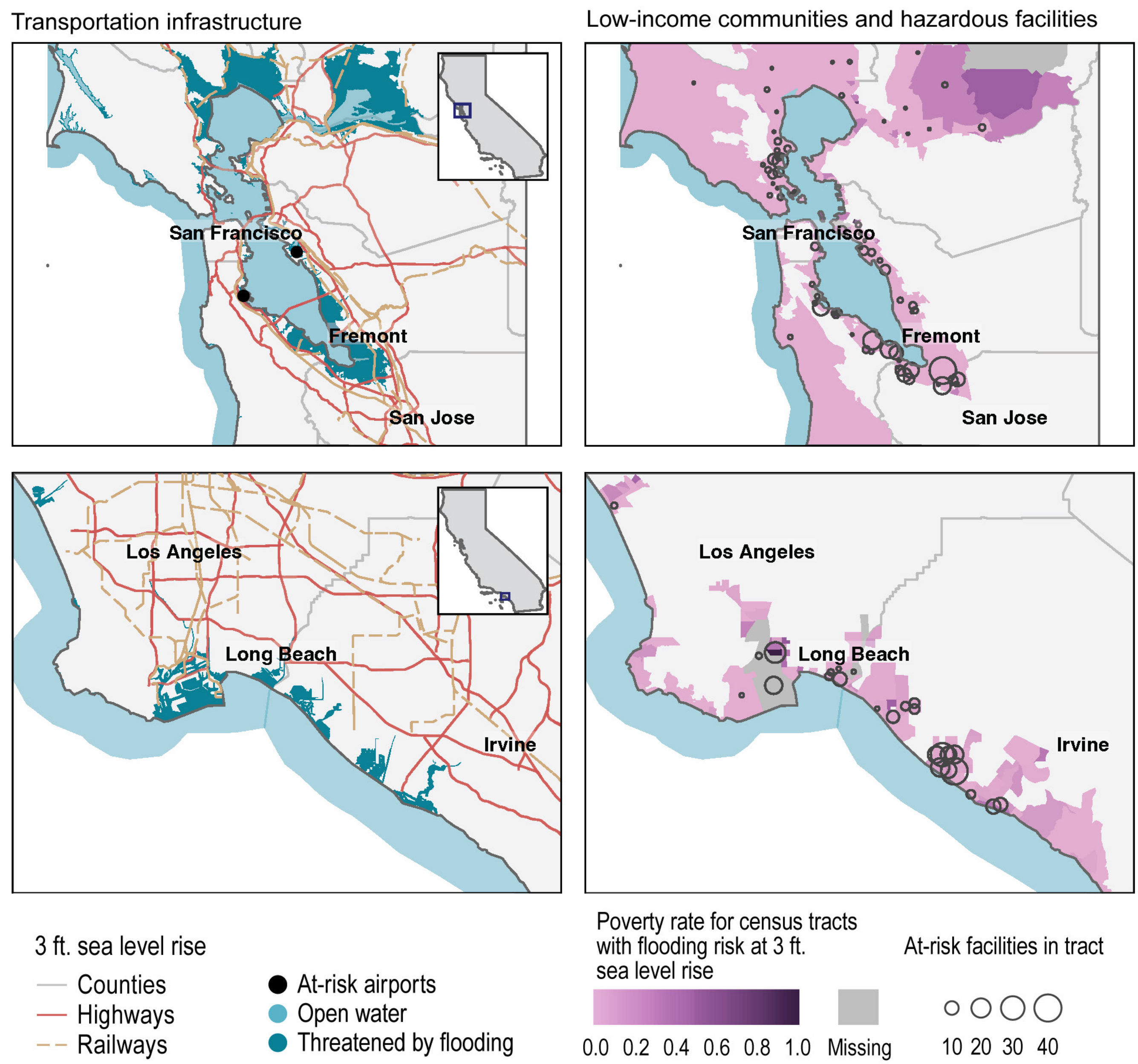
Potential adaptation solutions include an ecosystem management approach to marine habitats and fisheries, as well as enforcing water and land-use regulations, which are expected to buffer some climate impacts.[128] Protection and restoration of foundational eelgrass and kelp forests in California waters provides essential habitat, and these ecosystems can also improve local pH and oxygen conditions.[129,130] The Fishery Ecosystem Plan adopted by Pacific Fishery Management Council in 2013 includes guidance on OA and hypoxia,[128] but additional strategies—such as flexible permitting, better coordination with fishing communities, and adaptable control rules—may be needed to improve outcomes.[131] Nature-based aquaculture solutions, such as conservation and restorative aquaculture, also have potential to mitigate local OA impacts[132,133,134,135] but are just emerging in California.[136]

Sea Level Rise Impacts and Adaptation Planning

Sea level rise (SLR) poses risks to the California coast through an increase in flooding, impacts from storm surges, and loss of coastal habitats and beaches (Figure 28.5; KM 9.1). Seas are projected to rise, on average, 0.79–1.25 feet for the California coastline by 2050, 3.10–6.63 feet by 2100, and 6.11–11.90 feet by 2150 (Intermediate to High scenario).[7] California has more people living below 3.3 feet (1 m) of elevation than any other state except Louisiana;[137] the population living in the mapped 100- and 500-year coastal floodplains increased approximately 10% from 2010 to 2020.[137] SLR is also expected to exacerbate inequities in communities and result in compounding impacts, such as saltwater intrusion polluting groundwater.[7,138,139,140,141,142,143] Furthermore, coastal Tribes in California are observing rising sea levels, which, when combined with the loss of kelp forests, are increasing the risk of coastal erosion, destruction of cultural artifacts, and limited access to traditional shoreline sites.[110]

By 2050, for all emissions pathways, SLR effects on tide and storm surge are expected to cause more frequent moderate to major high tide flood events, and coastal communities are already experiencing minor to moderate high tide flooding (KM 9.1).[7]

Sea Level Rise Risks to Infrastructure and Communities



Flooding from sea level rise is expected to affect transportation infrastructure and communities along the California coast, with disproportionate impacts on lower-income communities.

Figure 28.5. These maps show the projected flood risk from 3 feet of sea level rise (SLR), as well as risks to critical infrastructure and surrounding communities, for the San Francisco Bay Area (**top row**) and the coastline from Los Angeles to San Diego (**bottom row**). Panels in the left column show transportation infrastructure threatened by flooding with 3 feet of SLR, while those in the right column show the number of hazardous facilities (indicated by circles) and census tracts at risk of flooding, with purple shading indicating the fraction of population in each census tract with income below the poverty level. Flooding from SLR will impact major transportation infrastructure along the coast; given the locations of hazardous facilities and their overlap with lower-income communities, this flooding will have disproportionate impacts on these communities. Flood risk from SLR is consistent with an Intermediate scenario in the year 2100.[7] Transportation infrastructure includes major airports, highways, and railways. Hazardous facility categories defined by EPA include manufacturing plants, power transmission plants and substations, natural gas pipelines, refineries and oil and gas wells, waste management facilities, landfills and incinerators, and animal operations. Figure credit: Eagle Rock Analytics.

Coastal energy and transportation infrastructure is expected to be negatively impacted by flooding from SLR. The projected inundation of energy substations in low-lying areas during storm events and from extreme SLR under a very high scenario (RCP8.5) is expected to cause electricity service interruptions to thousands of customers and increase maintenance and repair costs.[139] Analysis of California's transportation fuel network found that docks, terminals, and refineries are most exposed to coastal flooding.[143] The California Department of Transportation has begun adaptation planning efforts that consider a variety of strategies beyond hardening infrastructure, including nature-based strategies to limit the impacts of flooding (KM 8.3), as well as planning to avoid loss of coastal resources and access.[144]

Sea level rise and increased coastal flooding will disproportionately impact frontline communities (KM 9.2).[145] The Toxic Tides project found that under a very high scenario (RCP8.5), SLR in California[146,147] would result in increased flooding to over 400 industrial facilities and contaminated sites, including power plants, refineries, and hazardous waste sites, with 440 projected to be at risk of at least one flood event per year by 2100.[148] Any flooding of hazardous sites would increase risks of contamination in surrounding frontline communities.[149]

Residents of affordable housing, typically low-income communities, are especially vulnerable to SLR, with a greater percentage of affordable housing exposed to SLR than the general housing stock in some coastal states.[140] California is in the top four states nationwide with the most units of affordable housing exposed at least four times per year to coastal flooding based on projected sea levels for the year 2050 under a very high scenario (RCP8.5).[140] By 2050, California is also projected to see a 40% increase in the number of units at risk of flooding, compared to 2000.[140] For affordable housing residents, flood risk is compounded by the threat of displacement due to rising property values and rents. Strategic city-level adaptation and resilience efforts, combined with community and infrastructure improvements, could protect these residents from potential displacement.[140,150]

Higher seas are raising the coastal groundwater table, exposing communities to flooding from water that emerges from underground (KMs 9.1, 9.2).[138,141] Communities in low-lying areas such as San Francisco Bay are most at risk, and areas with shallow coastal water tables are projected to see widespread flooding from groundwater emergence.[138,141] Subsidence exacerbates this threat; coastal residents residing in subsiding locations experience an average relative sea level rise of up to four times faster than the global rate.[142,151] These risks have not been well addressed in adaptation planning. Furthermore, the impacts and adaptation needs are expected to be higher than reported if only overland flooding due to SLR—which does not include flooding from subsidence or groundwater intrusion—is considered in community and infrastructure planning.[142]

Adaptation planning for SLR as a field has advanced,[152] as coastal managers have reported an increased concern regarding the threat of SLR and local, regional, and state governments in California apply climate science to decision-making (KM 9.3).[153] California has instituted policies requiring consideration of climate change in state and local government decision-making and infrastructure planning.[154,155,156,157] Specifically for the coast, there is guidance on how to apply SLR risk assessment and projections into planning, including specific guidance for critical infrastructure.[158,159] This landscape of statewide policy and guidance is directly informing local coastal adaptation planning. Of 19 coastal counties, 18 have completed a vulnerability assessment, developed an adaptation policy, and/or updated the state-mandated safety elements of their general plans to include climate adaptation.[160]

While adaptation planning along the California coast has advanced significantly, many of these efforts have not yet been implemented.[160] This is partly because of financing and implementation challenges, especially for local governments that lack resources and must overcome institutional and governance issues (KM 31.5).[152,161] Despite these challenges, California is ahead of many other parts of the US coast in employing adaptation strategies and appears to be well positioned for increased adaptation.[152]

Key Message 28.3

Increasing Challenges Confront Food and Fiber Production in the Southwest

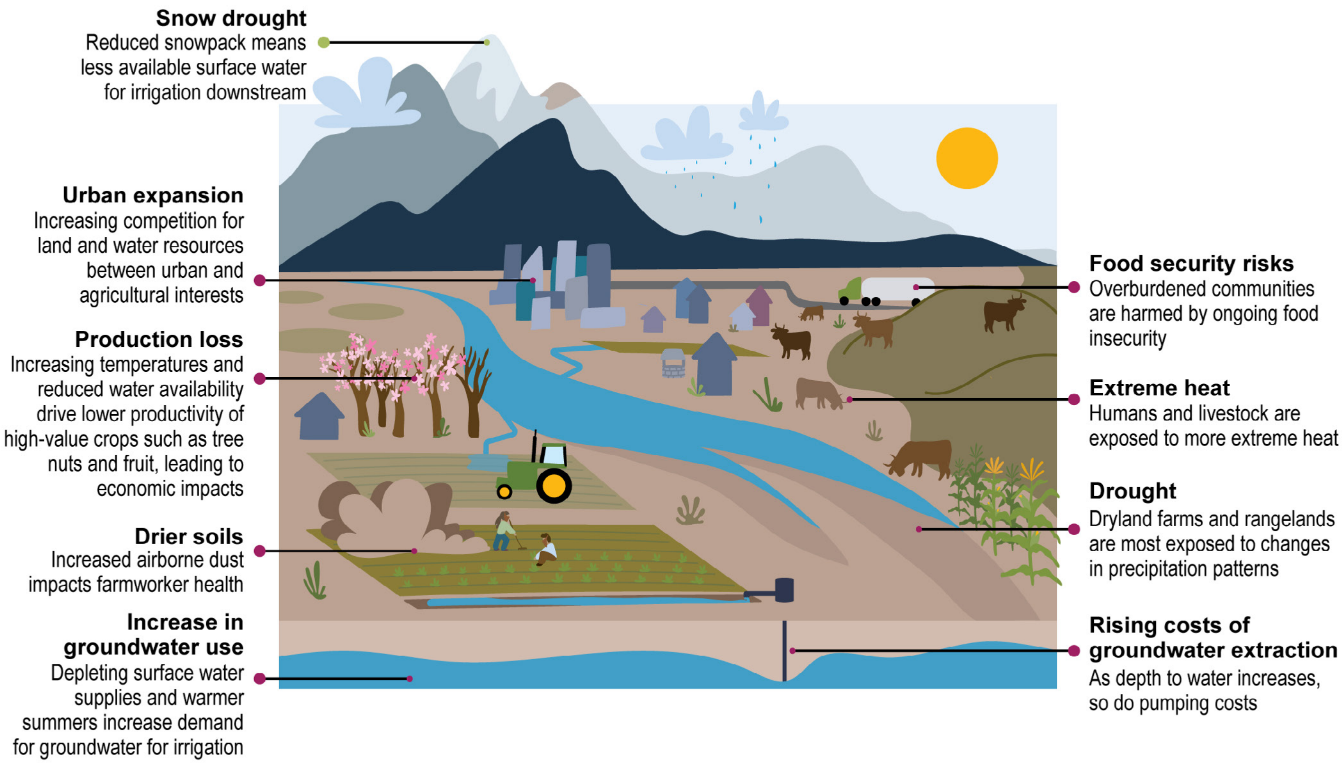
Continuing drought and water scarcity will make it more difficult to raise food and fiber in the Southwest without major shifts to new strategies and technologies (*high confidence*). Extreme heat events will increase animal stress and reduce crop quality and yield, thereby resulting in widespread economic impacts (*likely*, *high confidence*). Because people in the Southwest have adapted to drought impacts for millennia, incorporating Indigenous Knowledge with technological innovation can offer solutions to protect food security and sovereignty (*medium confidence*).

Across the Southwest, annual average minimum air temperatures, growing degree days, and average number of days above 86°F (the threshold used to define heat zones) are projected to increase due to climate change.[162] By midcentury under intermediate (RCP4.5) and very high (RCP8.5) scenarios, projections show longer growing seasons, a northward shift in plant hardiness zones, and expanded areas of heat stress exposure to crops and livestock (KM 11.1).[162] In California, increasing temperatures are expected to affect the timing of cool-season annual crops and the location of warm-season annual crops.[163] Warmer winters would be detrimental to the chilling requirements for orchard crops.[164] In California, fewer cold snaps are expected to reduce crop exposure to frost;[165] however, "false springs" in the intermountain West are expected to increase vulnerability to late-season freeze events.[166] During summer, a higher probability of heatwaves is expected (KM 2.2).[167] The productivity of some economically important crops, such as upland cotton in Arizona, has already declined because of heat stress.[168] While increased drought is the most prominent climate-driven risk to agriculture in the region, important farming areas such as California's Central Valley also face damage from occasional large floods caused by atmospheric river events.[169]

Impacts to Farming

Farmers and ranchers are particularly at risk from prolonged, severe drought (Figures 28.6, 8.6). Future temperature increases are expected to drive higher rates of evapotranspiration, increasing demand for fresh water for irrigation.[168] The producers most vulnerable to local precipitation deficits are dryland farmers growing rain-fed crops and producers raising livestock on rangelands. Community-based snow-fed irrigation systems in high-elevation watersheds of New Mexico and Colorado, known as *acequias*, are particularly exposed to the shortfalls in annual snowpack.[170] Under increasing aridity, agricultural practices such as fallowing and grazing on rangelands will need careful management to avoid increased wind erosion and dust production from exposed soils.[171] Rising summer temperatures also degrade protective desert soil crusts formed by communities of algae, bacteria, lichens, fungi, or mosses, adding to airborne dust loads.[172] The impacts of increasing aridity on agriculture are therefore twofold because dust deposits on mountain snowpack drive faster melting, depleting the snowpack[173] and resulting in reduced surface water for irrigation. While just 22 of the 216 counties in the region are classified as "farming-dependent" by the USDA,[174] agriculture is an important contributor to state and local economies and US food supply. California leads the Nation in agricultural cash receipts,[175] primarily from fruits, nuts, and vegetables; direct farm sales to consumers; and farm expenditures.[176] Climate change poses risks to both productivity and quality of fruit and vegetable products, requiring adaptations on farms and throughout the supply chain, including changes in crop calendars, nutrient and pest management strategies, post-harvest handling, and preservation methods.[177,178]

Agriculture and Climate Change in the Southwest US



Monitoring indicators of climate impacts on agriculture can improve understanding and help with adaptation efforts.

Figure 28.6. Climate change impacts to the Southwest's agriculture include longer growing seasons, a northward shift in plant hardiness zones, expanded areas of heat stress, and higher rates of evapotranspiration, increasing demand for fresh water for irrigation. Monitoring the indicators helps us understand how impacts are experienced and how to adapt to risks. Figure credit: New Mexico State University and Utah State University. See figure metadata for additional contributors.

Reduced crop production due to climate change will carry major economic costs. Drought events have brought significant economic impacts on regional agriculture (KM 19.1); for example, the 2021 drought cost California farming sectors an estimated $1.28 billion (in 2022 dollars) and led to the loss of 8,745 full- or part-time jobs (KM 11.3).[179] Modeling studies indicate that warming temperatures are expected to have a detrimental impact on the yields of almonds,[164] wine grapes,[180] and other high-value crops.[169] Localized adaptation strategies include crop- and locality-specific combinations of irrigation, site management (e.g., use of cover crops and increased fallowing), and cultivar selection.[181] Fallowing as a response to water shortages can bring its own challenges, such as increased dust and weed production, but it can also enhance ecosystem services such as groundwater recharge and improved ecosystem health.[182]

Climate warming is likely to lead to larger, more frequent, and more severe outbreaks of bark beetles, negatively affecting the quality and quantity of timber available to the region's forestry and forest products industries.[183] While wood products are minor economic contributors to the region's inland states, costs could be considerable in California, where the industry has been estimated to contribute $44.8 billion (in 2022 dollars) and 177,000 jobs (KM 7.2).[184]

Over time, agricultural income in the region has become more dependent on crops than livestock.[185] Because most Southwest croplands are irrigated, agriculture in the region had been thought to be less vulnerable to climate change than that in other parts of the country. However, future irrigation supply is uncertain as it depends on dwindling ground and surface water supplies (KMs 28.1, 4.1). For example, Arizona allows up to 73% of its water to be used for crop production,[186] but the promise of continued irrigation water is less clear given the state's rapidly growing population and decreased flows in the Colorado River.[187] Crop irrigation, mainly of alfalfa, accounts for three-quarters of consumptive water use in the Great Salt Lake basin, where cuts to irrigation use are advocated as the state seeks to prevent total depletion of the lake and associated environmental and public health impacts.[188] Strategies to reduce irrigation water use include switching from gravity flow and sprinklers to more efficient systems,[186] but the costs of conversion can be difficult for farmers when climate change is already reducing yields.[185] Federal insurance programs can assist farmers after climate-related crop or forage loss, providing short-term economic relief from effects of extreme events.[189] However, some research suggests that federal insurance programs provide a disincentive for farmers to adapt to climate change impacts.[189] Non-climate-related stressors can influence the capacity of agricultural communities to adapt to climate impacts.[29] On the plains of Colorado and New Mexico, most rural counties are depopulating due to persistent out-migration of young adults, straining social services and reducing tax revenues.[190] Yet the Southwest also has some of the fastest-growing areas in the US, including high-amenity rural areas and cities expanding into agricultural zones.[191] Urban expansion can increase cropland loss while simultaneously increasing the number of small farms focusing on specialty crops rather than basic commodities,[192,193] placing greater pressure on the region's food supply as drought (KM 28.1)[51] threatens agricultural production.[194]

Livestock production is the dominant use of agricultural land in large areas of the Southwest where crop production is unprofitable or infeasible. Animal agriculture accounts for about one-third of agricultural revenue, with about 70% from cattle.[195] Climate change is expected to reduce the sustainability of cattle production that depends on rangeland ecosystems.[195,196] Negative impacts are expected on the entire livestock food supply chain, affecting production and nutritional quality of forage, livestock health on rangelands and in transport due to heat stress and pest exposure, and shelf life of products during transport and storage.[197,198] Forage from Bureau of Land Management rangelands is expected to decrease in Arizona and New Mexico, but it is less certain whether rangeland forage will hold steady in the central and northern portions of California, Colorado, Nevada, and Utah due to differences in moisture availability during the growing season.[197,199]

Cascading Impacts of Climate Change to Agriculture

The cascading impacts of climate change in combination with urban population increases and other social and cultural factors pose an increasing threat to agriculture in the region.[29] Urban growth in the Southwest has led to competition for water between farms and cities, mirroring global trends.[200] Water transfers from rural to urban areas have been a feature of the Southwest for decades, often with negative consequences for rural and low-income communities.[201,202] To meet water demands for a growing metropolitan region while preserving irrigated croplands, Colorado is experimenting with water policy innovations designed to encourage rural-to-urban transfers while minimizing impacts in rural areas, but adoption has been slow due to distrust on the part of agricultural communities and uncertainty about trade-offs.[202] Market forces in California have encouraged growers to shift to crops with a high economic value but also a large water footprint, such as tree nuts[203,204] and legal cannabis.[205]

Frontline Communities and Food Insecurity

Frontline communities including Hispanic populations, women farmers, migrant farmworkers, and Indigenous Peoples face challenges to water access in their homes as well as food security and health (KM 4.2).[201,206,207] For example, the 2012–2016 drought in California's San Joaquin Valley disrupted farmworkers' employment and reduced food security, water security, and health.[208] Mental health risks are also increasing as farmers and ranchers report moderate to severe levels of anxiety about climate change and the need to adapt.[209] First-generation and women ranchers are disproportionately vulnerable to climate impacts because of limited experience with drought and weaker connections to rancher networks.[210]

Low-income urban communities are expected to be among the first to suffer food insecurity as climate change reduces the region's food production. Strategies have been proposed to produce more food in urban settings, but these foods often do not reach low-income consumers, who have less access to food distribution systems and often cannot afford to pay the higher prices such foods often command.[211] Indigenous Knowledge has been proposed as a significant resource for climate change adaptation (KM 16.3).[212,213] Because people in the Southwest have adapted to drought impacts for millennia, employing Indigenous Knowledge can allow the region to serve as a "laboratory" for future climate-adapted food systems[214] while enhancing food sovereignty.[215]

Adaptation for Agriculture

Adaptation solutions exist for ranching operations,[196,216] but social and economic barriers, such as distrust of experts, the financial costs and time commitments of innovation, and adherence to tradition, have slowed information uptake.[199] Climate change information is not routinely incorporated into ranchers' risk management decisions[217] and only recently has become a priority in federal agency rangeland management plans.[197]

People across the Southwest are exploring technological adaptations to climate impacts (KM 31.3). Adaptive conservation management approaches that focus on minimizing soil disturbance while maximizing soil cover, biodiversity, and the presence of living roots have been gaining traction with farmers through practices such as cover cropping and reduced-tillage and no-till farming (KM 11.1).[218,219] Combined with reduced tillage, cover cropping improves soil structure, organic carbon content, and infiltration and water-holding capacity in irrigated cropland[220] and positively impacts nutrient cycling, crop yield, and soil water conservation in limited-irrigation, semiarid cropping systems.[221,222] However, some farmers and ranchers, such as those who operate on small acreages, often find it hard to access the resources to transition practices or may perceive the risks of change to be too great, including financial expense and the perceived need to learn new skills.[223]

Irrigation efficiency can reduce risks to farming and ranching operations due to increasing temperatures, unreliable precipitation, and reduced water resources. However, access to these solutions can be complicated due to farm or ranch location, access to surface water and groundwater, water rights, current irrigation methods, and crop types.[224] In the Verde Valley of Arizona, limited access to materials, equipment, and financial resources, especially for small-scale producers, inhibits their ability to respond to water-related challenges.[224] Indigenous Peoples face barriers in accessing support from the Natural Resources Conservation Service (NRCS) related to land tenure, financial assistance, institutional mismatches, and complexities in incorporating Indigenous agricultural methods in applications for NRCS programs.[225,226]

Key Message 28.4

Climate Change Compromises Human Health and Reshapes Demographics

Increases in extreme heat, drought, flooding, and wildfire activity are negatively impacting the physical health of Southwest residents (*high confidence*). Climate change is also shaping the demographics of the region by spurring the migration of people from Central America to the Southwest (*medium confidence*). Individuals particularly vulnerable to increasing climate change impacts include older adults, outdoor workers, and people with low income (*high confidence*). Local, state, and federal adaptation initiatives are working to respond to these impacts (*high confidence*).

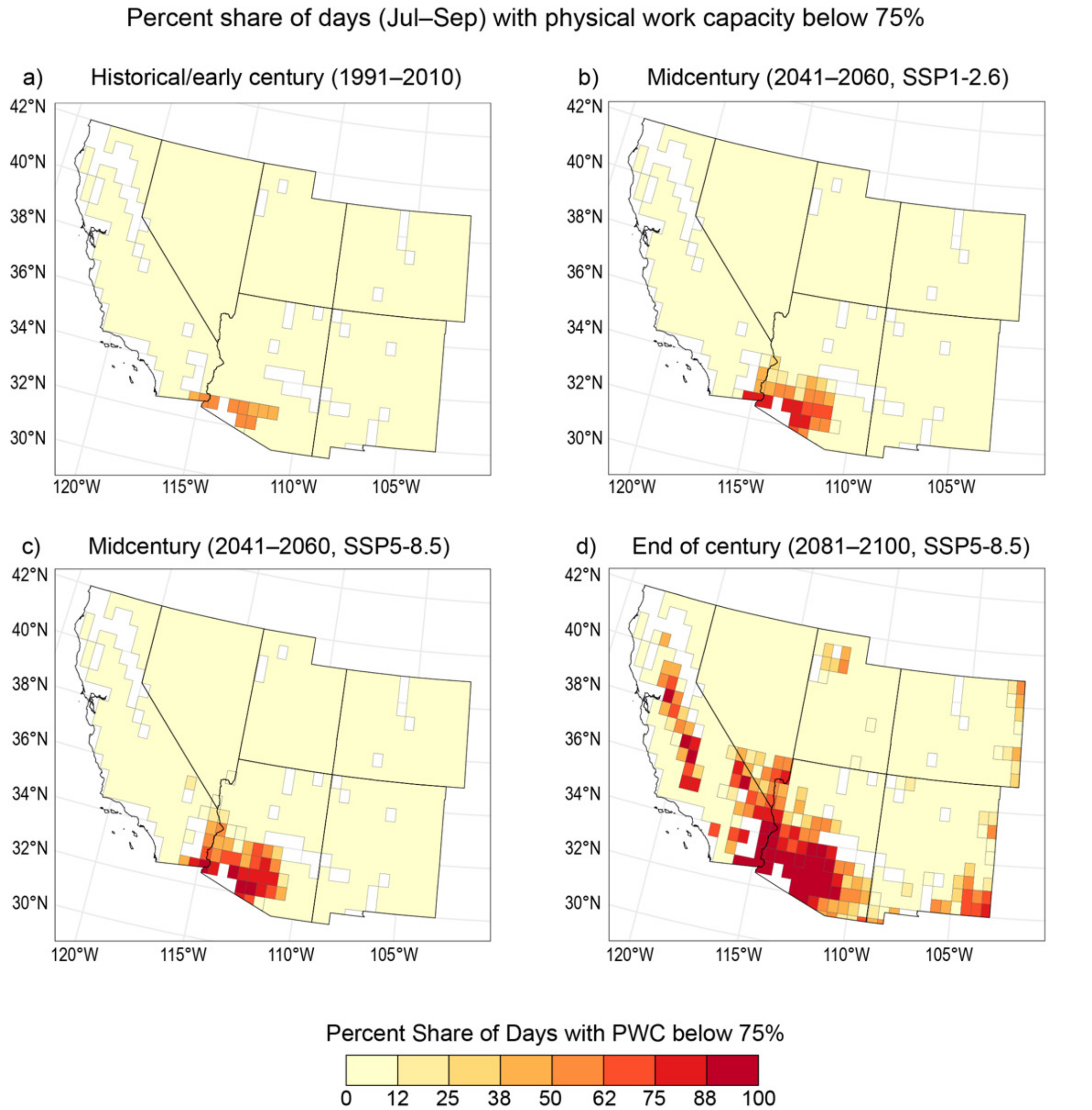
Extreme Heat Impacts

Since 2018, 31 large climate- and weather-related disasters have affected the Southwest, resulting in more than 700 fatalities and estimated damages totaling $67.3 billion (in 2022 dollars).[2] Strong evidence indicates that extreme heat disproportionately impacts the health of frontline and overburdened communities in the region (KM 15.2), including the unhoused,[227,228,229] outdoor workers, and migrant farmworkers (Figure 28.7; KM 11.2),[230,231,232,233] as well as those with low income[8,234] and older adults.[235] Between 2016 and 2020, 7,687 hospitalizations in the Southwest were due to heat and heat-related illnesses, in comparison to 5,517 in the previous five years (2011 to 2015).[236] Pre- and post-natal exposure to high heat and air pollution are shown to be particularly dangerous in the region.[237,238,239,240]

Extreme heat and high-ozone days in the region are expected to increase under climate change (KMs 2.3, 3.5).[241] These changes are expected to increase heat and air-pollution exposure, illness, and premature death.[242] Intensified aridity from higher temperatures and drought is expected to lead to more dust storms[243] and more than double the number of deaths attributed to fine dust by 2080–2099 under a very high scenario (RCP8.5), relative to 1986–2005 (KM 6.1),[244] with increasing exposures for outdoor workers during the warm season. The incidence of coccidioidomycosis (Valley fever) in the region has increased (Figure 15.2)[245] and is associated with higher air temperatures and drier soils,[246,247] with greater risk to those whose job requires dirt disruption. The annual average cost to the US economy of Valley fever for the 2000–2015 baseline was $4.8 billion per year (in 2022 dollars), which is projected to increase 390% by 2090 under a very high scenario (RCP8.5; Figure 15.2).[248]

Extreme heat exposure also affects the economy through decreased productivity and well-being in outdoor workers (Figure 28.7),[249,250,251] especially among migrant agriculture workers in the region (KM 15.1).[252,253] Impact estimates to productivity provided in Figure 28.7 are projected to result in a loss of 25% of the workday on all days in the third quarter (July–September) under a very high scenario (SSP5-8.5) by the end of century and cause important losses to the economy (KM 19.1). Dehydration due to working outdoors in extreme heat in California is linked to acute kidney illness even after a single day of exposure.[254] Research into the mechanisms of chronic kidney disease related to climate change is ongoing, yet occupational heat exposure is a causal factor.[255]

Heat Impacts in the Southwest



With extreme heat events expected to increase in frequency and severity, the ability to perform work outside is projected to decline across parts of the Southwest.

Figure 28.7. The ability to perform work outside—as measured by physical work capacity (PWC)—will decline across large swaths of the Southwest due to heat exposure throughout the century, with the greatest declines expected in southwest Arizona, southeast California, and California's Central Valley. These impacts on outdoor work will affect agricultural output, as well as earning ability for workers. PWC has a range of 100% (no loss of work capacity) to 0% (complete loss). The maps display the proportion of days in the third quarter (July to September) in which PWC is less than 75%. In historical conditions (**a**), a few locations in southern Arizona had PWC values less than 75% for half of the quarter. (**d**) Under a very high scenario (SSP5-8.5) by end of century, most of southern Arizona, southeast California, and some of California's Central Valley are projected to have less than 75% work capacity for all days in the third quarter. This daily labor loss is calculated based on a given heat load (temperature, humidity, and solar radiation) compared to temperate conditions where there is no thermal effect on work output. To provide a full range of potential impacts, maps are based on representative years for (a) historical/early century (1991–2010); (**b**) midcentury (2041–2060, SSP1-2.6 [low scenario]); (**c**) midcentury (2041–2060, SSP5-8.5 [very high scenario]); and (d) end of century (2081–2100, SSP5-8.5). Estimates are based on an individual performing moderate to heavy agricultural work outdoors over a daytime shift (about 7 hours). The PWC is an empirical estimate based on human physiological chamber studies quantifying how PWC changes with the environment heat load based on the wet-bulb globe temperature.[256,257,258,259] Land areas in white had no crops in the early 21st century. Figure credit: University of Illinois–Urbana Champaign and Arizona State University.

Air Quality and Health Impacts

While the annual average level of fine particulate matter ($PM_{2.5}$) has seen decadal decline in the region due to strengthened air quality policies reducing emissions from controllable sources, disparities in $PM_{2.5}$ exposure and related health concerns remain high in the region.[260] Moreover, the frequency and severity of smoke events with $PM_{2.5}$ exceedances of federal air quality standards have increased significantly due to wildfires (Figure 14.3). Since 2015 in Northern California, the annual average $PM_{2.5}$ has increased because of wildfire events, which have taken over as the main source of $PM_{2.5}$ exceedances.[261] $PM_{2.5}$ in wildfire smoke contributes to adverse health effects for firefighters[262] and the public[263,264] and can be more hazardous to health than similar levels of particulates from other sources.[265] The costs of adverse respiratory and cardiovascular health outcomes can exceed the billions spent on wildfire suppression (KM 28.5).[266] Chemicals in wildfire smoke also correlate with increased cancer risk.[267] Direct exposure to the 2018 Camp Fire in California has been linked to mental health disorders such as depression and post-traumatic stress disorder.[268] Wildfires can also cause other public health impacts, including water contamination when fires damage water distribution infrastructure,[269] long-term loss of access to clean drinking water,[270] and increased landslide risks (KM 28.5).

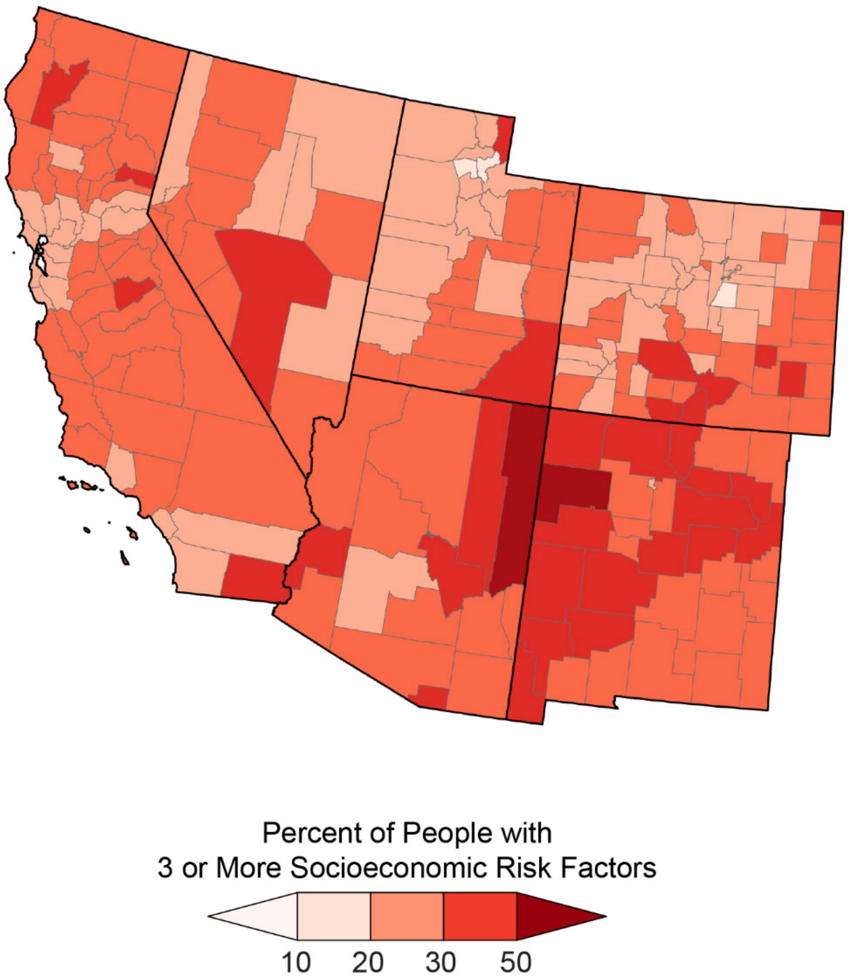
Flooding and Disease

Increases in flooding in the region are projected with continued warming.[271,272] These changes increase risks of water-borne diseases and exposure to toxic hazards and place stress on food, energy, and water supplies, as well as farmworkers' health (including interconnected sectors) and their socioeconomic insecurity.[39] Flooding exposures may increase as a greater proportion of the population across the region, on average, is living on 100-year floodplains (e.g., in California, between 1990 and 2020, 25,000 more people lived on 100-year floodplains).[137] Flooding can also interrupt vector-control programs, such as for West Nile virus.[273] The region is seeing challenges with West Nile virus, particularly in Arizona and California,[274] with projected increases due to changes in the climate, human population, and mosquito distribution (KM 24.3).[275,276]

Impacts to Outdoor Workers

Limited occupational health and safety standards for farmworkers and other outdoor workers are of key concern, as intensifying wildfires and heat collide with harvest season each year, particularly for undocumented Latino/a and Indigenous migrants.[231] The improvement of these standards at the state and national levels will be critical for health adaptation to climate impacts in the region. Moreover, the harm to farmworkers due to wildfire smoke is expected to be greater than previously thought, bolstering the argument for additional research and policies to help safeguard overburdened and stigmatized populations.[277] Many Southwest cities experienced high rates of economic and population growth during the second half of the 20th century, particularly between 2015 and 2019.[31] The region's flourishing economy and proximity to the Mexican border result in a high influx of migrants.[278,279] Migrants from Central America, spurred to migrate due to climate change in addition to poverty and violence (KM 17.2), are drawn by the Southwest's strong economy and increase the number of vulnerable people and change the demographics in the region. Local, state, and federal efforts to both mitigate climate change and support essential human adaptation to increasing exposures will be vital in protecting the health of a growing and aging population and our most vulnerable communities (Figure 28.8; KM 15.1).[280]

Community Resilience Estimates for the Southwest



Communities with higher socioeconomic risk factors are expected to be less resilient in the event of climate and weather disasters.

Figure 28.8. The map shows community resilience estimates (CREs) for the Southwest. Community resilience is the capacity of individuals and households to absorb, endure, and recover from the health, social, and economic impacts of a disaster. Individual and household characteristics from the 2019 American Community Survey were modeled, in combination with data from the Population Estimates Program, to create the CREs at the county level. Darker shading indicates a higher proportion of the population at risk. Adapted from US Census Bureau 2021.[281]

Demographic Shifts Related to Climate

The effects of climate change on other regions of the world—especially Central America—are changing the Southwest's demographics. Decreasing agricultural productivity, increasing levels of food insecurity, and adverse climate effects are among the main reasons why people emigrate from the Northern Triangle (Guatemala, Honduras, and El Salvador) to the US (KM 17.2).[32,279] In 2021, 42% of Central American immigrants to the US lived in the Southwest region,[282] and about 43% of immigrants apprehended at the Southwest border in 2019 originated from the Northern Triangle.[278] Many are poor, women, children, or Indigenous Peoples. Climate-related migration has been shown to affect people's physical and mental health, resulting from exposure to weather extremes, disruption of social ties, and overcrowding of health systems in the host communities.[283]

Adaptation Efforts for Health

Several programs have been developed to address the health impacts of climate change in the region, but financial constraints and political support affect their implementation.[284] Since 2010, the CDC's Building Resilience Against Climate Effects program in Arizona and California has developed and implemented strategies to protect communities from climate-sensitive hazards, including schools, healthcare facilities, and other at-risk populations.[285] This program, currently in 10 cities across the country, has developed important resources and programs that can be scaled up for future climate resilience efforts. To protect the health and learning of school children, the Arizona Department of Health Services created new heat policy guidance, resulting in recommendations for school heat safety and adaptation strategies.[286,287] In California, San Mateo County assessed asthma burden connected to local climate issues.[288] Public health guidance in the region should focus on co-exposures to heat and wildfire smoke in adaptation efforts,[289] particularly given the projected increase in childhood asthma due to wildfires.[290] While data on private sector investment is limited, the private sector has historically lacked incentives to invest in adaptation (KM 31.6). Globally, in 2017–2018 only 1.6% of all adaptation financing came from the private sector.[291] In the Southwest, however, certain sectors, such as insurance, came under pressure from the local authorities to get involved in tackling climate change by divesting their fossil fuel–based investments.[292]

Key Message 28.5

Changes in Wildfire Patterns Pose Challenges for Southwest Residents and Ecosystems

In recent years, the Southwest has experienced unprecedented wildfire events, driven in part by climate change (*high confidence*). Fires in the region have become larger and more severe (*high confidence*). High-severity wildfires are expected to continue in coming years, placing the people, economies, ecosystems, and water resources of the region at considerable risk (*very likely*, *high confidence*). Opportunities for adaptation include pre- and postfire actions that reduce wildfire risk and facilitate ecosystem restoration and include traditional land stewardship practices (*high confidence*) and the application of Indigenous cultural fire (*medium confidence*).

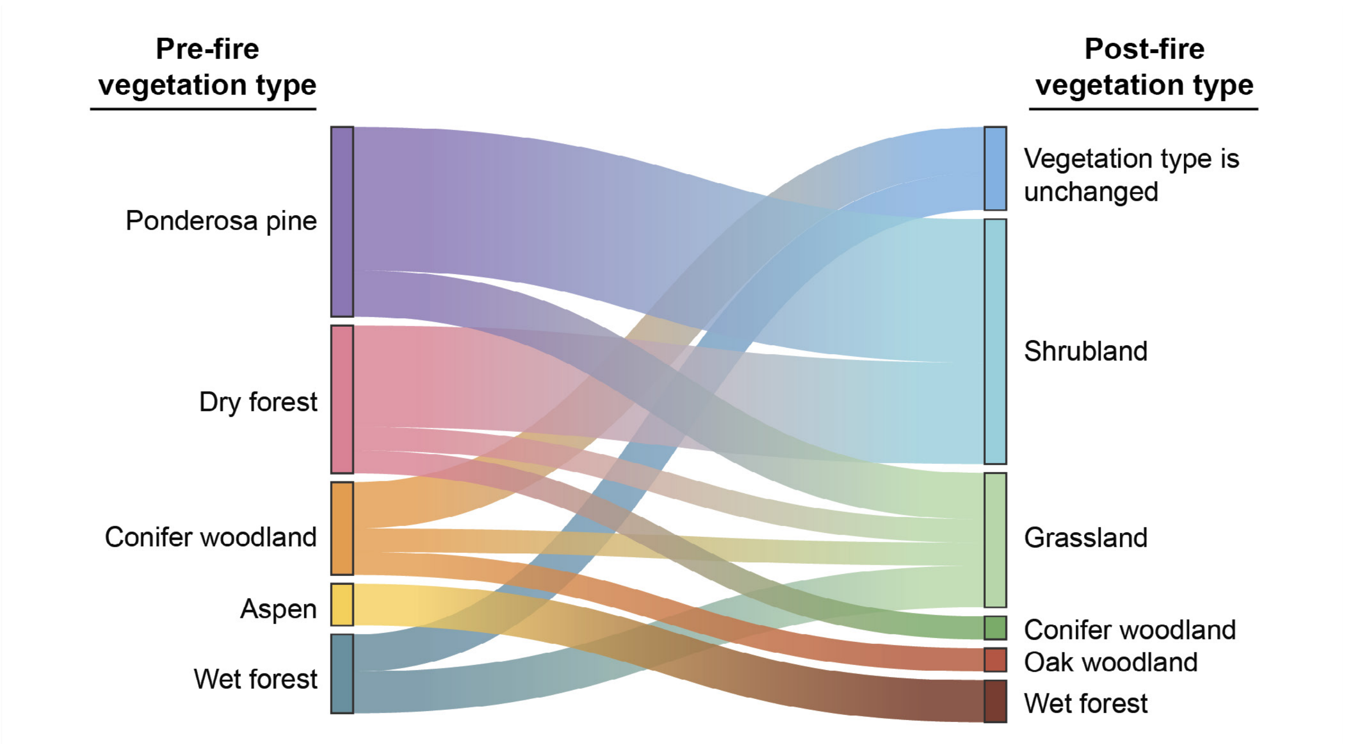
Fire is a natural process in many ecosystems across the Southwest and is necessary for biodiversity, ecosystem services, and nature-based solutions (KM 8.2). Fire regimes associated with fire-dependent ecosystems are highly variable with elevation and across geographies.[293] Long-standing policies and forest management—including fire suppression, widespread logging and livestock grazing, and elimination of Indigenous fire use—combined with the effects of a changing climate, have contributed to high tree densities, compromised ecosystem function, and the diversity, or heterogeneity, of forest attributes such as species, size classes, and geographic distributions.[18,21,294,295,296] Consequently, many Southwest forests and fire-prone wildlands are susceptible to climate-mediated impacts including droughts, pests and disease (Box 7.1), and devastating wildfire.[295,297] An abundance of scientific research strongly suggests that Southwest ecosystems, in the face of rapid climate change–induced transformation, will require active management interventions that increase forest heterogeneity and enhance ecosystem function and adaptive capacity (KM 7.3).[298,299,300]

Human-induced warming temperature trends, changes in precipitation patterns, and increases in vapor pressure deficit have driven the desiccation of fuels that influence wildfire patterns and behavior across the western US (KM 7.1).[17,18,19,20,21,301] In the Southwest, fires have become larger, more frequent, and, in many areas, more severe (KM 7.1), with clear evidence of climate change as a major cause.[302,303] Seven of the ten largest US wildfires in 2020–2021 occurred in the region. Of the 50 largest US wildfires in 2020, 22 occurred in California, and the 7 largest wildfires recorded in California have occurred since 2018.[304,305,306] The three largest wildfires recorded in Colorado occurred in 2020; the largest fires in Nevada history burned in 2018;[307] and the largest wildfires in Arizona, New Mexico, and Utah all occurred since 2007 (Figure 28.9; Focus on Western Wildfires). Large fires on non-forested western US rangelands also increased more than fivefold during the period 1984–2017.[308] Much of this increase is driven by increases in invasive annual grass cover, caused partly by climate change and increased atmospheric carbon dioxide.[309]

Impacts on Ecosystems

Climate change causes cascading effects with other factors in Southwest ecosystems that are otherwise fire-adapted. For example, large areas of high-severity fire have driven ecosystem type conversions in many parts of the region.[294,310] Semiarid to arid forest systems are particularly vulnerable to these effects and have experienced conversion to native grassland,[311] shrubland, or non-native grassland (Figures 28.9, 8.6).[294] The cumulative effects of fire-driven ecosystem changes continue to place ecosystems at high risk of vegetation type conversion (e.g., forests to shrublands), which can result in severe impacts on watersheds and aquatic resources.[294] Effects include degradation of riparian systems; risks to riparian and riverine species, as well as to threatened and endangered species, from erosion caused by extreme precipitation events; and increased invasions by non-native species.[312]

Wildfire and Vegetation Change in the Southwest



Climate change is leading to larger and hotter fires and resulting in shifts in vegetation.

Figure 28.9. Data from the states of California, Arizona, Colorado, and New Mexico show that approximately half (about 50%) of vegetation type change (e.g., forests transiting to shrublands or grasslands) is a function of high-severity fire. Adapted from Guiterman et al. 2022[294] [CC BY 4.0].

Recent climate-induced aridification, including loss of snowpack, has also hindered postfire tree seedling and shrub establishment, limiting ecosystem recovery.[313,314,315] This is particularly true of postfire conditions for water availability, quantity, and quality. Moreover, interactions between wildfire and natural drought variability are expected to increasingly exacerbate dry conditions that will further stress tree seedlings[316] and drive potential future shifts in species composition or vegetation type.[314,317] Conversions of coastal shrublands driven by human development also have interacted with climate-induced drying of vegetative fuels to generate atypical fire conditions.[318]

Projections of future climate change suggest that wildfire activity will continue to affect ecosystems and their services.[298,319,320,321,322] Specific ecosystem responses to climatic changes will depend on interactions among vegetation type, moisture stress, disturbance regimes (e.g., pests, pathogens, and high-severity fire), and human land-use changes (KM 6.2).[295,297,319] For example, climate change is predicted to lead to a loss of sagebrush ecosystems in the southern and eastern Great Basin because those ecosystems are less able to recover after fires in a warmer, drier climate.[323]

However, future wildfire trends are less certain in rangelands than in forests because fire size (measured by annual area burned) and severity (a shift from low-intensity fires to stand-replacing crown fires) depend on production of aboveground vegetation that varies annually with climatic conditions.[324] Growth of the grasses that typically fuel wildfires is expected to decrease in Arizona and New Mexico,[199,325] whereas elsewhere in the region, precipitation is projected to increase early in the growing season, which, when followed by hotter summers, will generate conditions ideal for fire ignitions.[324]

Impacts on People and Communities

Climate-related increases in the frequency, severity, and extent of wildfires in the Southwest are endangering lives and property (Focus on Western Wildfires).[17,18,19,20,21,326] Complete data across the region on wildfire-caused fatalities are sparse,[327] but three of the five deadliest fires on record in California have occurred since 2017, costing 122 lives.[304] Further, loss of life can be attributed to wildfire smoke, which has also been linked to increases in COVID-19 fatalities in Northern California[328] and postfire debris flows that can leave slopes bare of vegetation and vulnerable to rapid erosion (Ch. 7; Focus on Western Wildfires).[329] The risk of postfire debris flows in coastal communities is expected to increase due to an increase in heavy precipitation typically delivered by atmospheric river events (KMs 28.1, 8.1).[330]

Property losses due to wildfire are greatest in the Southwest compared to other regions. In 2021, 3,363 structures burned due to wildfires in California, the highest number lost in any state, while the December 2021 Marshall Fire in Colorado, a fast-burning grassland fire, burned more than 1,000 homes in just a few hours.[306] The 2022 Calf Canyon/Hermit's Peak Fire that burned 341,735 acres is New Mexico's largest fire. Secondary impacts of wildfire, such as postfire debris flows (Figures 3.13, 6.5) on recently burned slopes, impose additional hazards to property.[329] The estimated cost of fighting the 10 largest California wildfires in 2021 exceeded $2.25 billion (in 2022 dollars),[306] with suppression costs representing only a fraction of a total economic impact that also includes loss of structures and infrastructure, increased medical costs, crop losses, water quality contamination, and other factors (KM 19.1).

The increase in structures and infrastructure lost can be linked to population growth in the wildland–urban interface (WUI; Figure A4.14), where houses are built close to forests and other natural areas.[331] The number of Americans living in the WUI doubled from 1990 to 2010, and the WUI population has risen fastest in areas such as the Southwest where wildfire risk is greatest.[332,333] While migration to WUI counties shows modest reductions immediately after wildfire or extreme heat events,[334] fires do not seem to drive current residents away; fewer than 6% of Sonoma County, California, residents who lost homes to wildfires in 2017 subsequently left the county.[335]

Impacts of fire on community livelihoods depend on exposure to wildfire risk and capacity to adapt (KM 7.3). Analysis of livelihood vulnerability in 14 fire-prone states found that New Mexico and Arizona residents were most vulnerable due to relatively high risk exposure and low to moderate access to resources needed to adapt to changing conditions.[336] Low-income areas, communities of color, undocumented Indigenous migrants, sexual and gender minorities (KM 15.2),[337] and unsheltered persons are most vulnerable to wildfire impacts,[231,338] including water contamination from carcinogenic compounds.[269] Populations with medical disabilities or limited mobility, older adults, and those who rely on medical equipment are also disproportionately at high risk during wildfires.[339]

Wildfires, moreover, often occur during farm harvest seasons, increasing health risks for workers.[277] Southwest industries especially vulnerable to wildfires include wineries,[340] tourism,[341,342] forest products,[183] and legal cannabis cultivation.[343] For example, in the 2020 fires, the economic impact of smoke taint is estimated to have cost the California wine industry $4.2 billion (in 2022 dollars). Smoke taint occurs when smoke and ash permeate the skin of grapes and can affect the taste and smell of wine.[344]

Impacts of wildfire on natural environments can affect ecosystem services (KM 7.2) that people derive from those environments, including air quality (KM 28.4),[266] water quality and availability,[345] pollination,[346] livestock forage and health,[347] and outdoor recreation.[348] Ecosystem service effects vary over time as short-term declines in services can be followed by improvement over a longer term as ecosystems recover.[349] Wildfires in forested ecosystems chemically alter watersheds and can reduce drinking water quality,[350] in some cases leading municipalities to issue drinking water advisories.[351] Postfire hazards such as floods and debris flows further threaten water security (Focus on Western Wildfires).[352] Smoke from the 2020 wildfires significantly reduced industrial solar energy production in Southern California.[353]

While high-severity wildfires (i.e., stand-replacing fire) generally have negative impacts, wildfires and prescribed fires that burn at low to moderate severities can have positive effects by reducing fuel loads, curtailing plant pests and diseases, and stimulating new vegetation growth.[354] Prescribed burning, while an effective tool to reverse undesirable changes in forest vegetation structure due to fire suppression, can also reduce air quality in the short term.[266]

Ecosystem Management Challenges and Adaptation Solutions

Forest resilience may be enhanced by thinning trees, leveraging low- and moderate-severity wildfires with traditional forest management treatments that adjust fuels, and better incorporating managed wildfire.[299] Using prescribed fire in conjunction with mechanical forest treatments, such as thinning or pruning, also reduces tree densities and fuels.[300] Prescribed fire can increase forest resilience during periods of climate-related stress, such as sustained drought,[355] and can reduce the extent and intensity of the wildfire regime.[356] Cultural fire use to meet Indigenous and Tribal objectives can be compatible with traditional fire application and help advance increased resilience to climate change.[296,357]

To decrease competition for water resources and increase forest resilience, reductions in tree density and fuels can lower the risk of high-severity wildfires and drought- and pest-induced mortality (KM 6.2).[358,359] Recent evidence suggests that increasing these approaches can help adapt to the rapidly increasing risks.[299,360] However, the implementation of prescribed fire may be curtailed due to public concerns about smoke and fires that escape management prescription.[361]

Natural lands, including forests and associated woodlands, play a central role in mitigating climate change (KM 32.1).[362,363] However, climate variability, drought- and pest-driven tree mortality, wildfire, and other disturbances suggest that the Southwest will see a continued decline in terrestrial carbon storage.[362,364] As a result, securing or even increasing ecosystem carbon storage is often an objective for forest management investment.[365] Forest management treatments differ in their short-term carbon losses relative to the expected benefits of greater fire resistance, which leads to longer-term carbon stability (Box 7.2). In Southwest forests, reducing thinning area and increasing the area burned enhances the potential for a net carbon benefit when compared to no action.[366] Reforesting areas where forest cover was lost due to mortality can help mitigate the effects of climate change,[367] but planting additional trees that increase forest density would result in elevated fire risk and drought stress and therefore is not expected be an effective adaptation solution.[300,368]

Other adaptation solutions include power shutoff policies by utilities to reduce wildfire risk when extreme wind events are predicted to topple powerlines and telecommunications infrastructure.[369,370,371] Power shutoffs are more likely in autumn due to a climate-related increase in the number of days with extreme fire weather.[18] Power shutoffs may also increase homeowners' intention to adopt solar power[372] or fossil fuel–powered generators.[373] Individuals who experienced shutoffs reported poorer physical and mental health immediately after the occurrence, yet they still supported the use of shutoffs as a wildfire risk-reduction strategy.[374]

Traceable Accounts

Process Description

Following their selection in August 2021, the chapter lead author, federal coordinating lead author, and agency chapter lead author developed a comprehensive list of author candidates based on an analysis of prior National Climate Assessments, published scientific literature, science communication outlets, and policy-relevant reports. The final chapter authors were then selected based on their depth of knowledge, diversity of expertise, and experience in issues critical to the Southwest. Furthermore, authors were selected to represent diverse perspectives in terms of race, ethnicity, and gender identity. The Southwest chapter public engagement workshop was held virtually on February 4, 2022, with more than 90 participants. The workshop included an overview, a series of breakout rooms where the participants provided feedback on key topics, and a final roundup discussion among all participants. The author team held a debriefing session on February 7, 2022, to reflect on the input provided during the workshop. The author team met weekly during the development of the chapter.

Based on discussions among the author team, input from stakeholders, and consideration of the Fourth National Climate Assessment, the authors developed five Key Messages representing the valued assets and unique characteristics of the region. These include water resources, the coast, food and agriculture, demographics and human health, and wildfire. The chapter details the observed and anticipated effects of climate change on human and natural systems across those topics and outcomes to be avoided in the absence of adaptation and mitigation.

For the scientific assessment, the authors conducted a systematic evaluation of the body of scientific and technical knowledge to synthesize published studies, data, models, and assumptions while applying best professional judgment to assess uncertainties and conflicting findings. The chapter pays specific attention to factors that make specific systems and groups more vulnerable. The chapter identifies intersections between topics, cascading risks, and paths to resilience. The chapter also addresses cross-cutting themes including adaptation solutions and challenges, climate change equity and environmental justice, Indigenous Peoples and Knowledges, economics, infrastructure, and ecosystems and ecosystem services.

Key Message 28.1

Drought and Increasing Aridity Threaten Water Resources

Description of Evidence Base

Instrumental data and paleoclimate data provide strong, abundant evidence that the early-21st-century drought in the Southwest is more severe than most, but not all, prior drought periods.[28,45,46,375] Research has identified higher temperatures as being a major driver of drought severity through the mechanism of increased atmospheric demand.[47] Recent research builds on an already-substantial evidence base demonstrating the decline of southwestern snowpacks over the last century.[5,6,49,50] Research has shown how drought-induced shortages in surface water have increased groundwater pumping in California's Central Valley,[67] which provides one example of how drought may reduce future water access, especially if aquifer recharge is also reduced.[63]

Major Uncertainties and Research Gaps

Historical data supply insight into the potential impact of precipitation deficits on surface water, and various research studies demonstrate how precipitation deficit and higher rates of evapotranspiration feed into reduced soil moisture and infiltration, both in contemporary and future warmer climates. However, there is remaining uncertainty over the precise contribution of temperature to these declines in 20th-century

Upper Colorado streamflow,[375] the impact of changing snowpack dynamics on streamflow in and across different southwestern river basins,[56] and the impacts of El Niño–Southern Oscillation on precipitation in the region.[376,377]

There are also research gaps on the impacts of climate change on the full hydrologic cycle of the Southwest. From the biophysical perspective, there's a lack of information about aquifer recharge, specifically regarding temporal variability of recharge rates and locations.[63] Another topic for further exploration is the relationship between drought, surface water supplies, and rates of groundwater pumping for agriculture in locations within the Southwest beyond California (e.g., Rio Grande and tributaries, Utah, Nevada). Further, there is limited research on climate change impacts on the dynamics of the North American Monsoon, including how to more effectively capture monsoon moisture to substitute for decreased winter precipitation, as well as on other extreme precipitation events such as atmospheric rivers.

Additionally, there are multiple paths for water adaptation in the Southwest for industry, agriculture, and communities to build resilience to a more water-scarce future. However, there are research gaps around the feasibility and long-term effects of these adaptation solutions.[378,379] Moreover, the ability of different sectors and communities—including rural, low-income, Indigenous, and other frontline communities—to adapt to climate-induced water scarcity is highly variable across the Southwest.[380] There is a gap in research on best practices to support these communities in adapting to current and future water scarcity.

Currently, Indigenous Peoples' water rights are under-utilized, while water access remains a challenge for many Indigenous Peoples. As more Indigenous Peoples gain access to and use their water rights, there is limited research on how this might impact other water users and broader water management actions, especially under Colorado River drought policies.[381]

Description of Confidence and Likelihood

Measurements of snowpack, streamflow, and groundwater over the last century support the observation, with *very high confidence*, that climate change has reduced surface water and groundwater availability for people and nature in the Southwest.[4,14,56] Moreover, evidence from the peer-reviewed literature supports the assertion of *high confidence* that certain Indigenous and frontline communities, including agriculturalists, will experience disproportionate impacts from reduced water availability and that long-standing institutional frameworks drive these inequities.[187,382,383,384]

The *high confidence* that higher temperatures have intensified drought and will *very likely* lead to a more arid future is based on recent evidence that shows that since the early 20th century higher temperatures have increased the proportion of precipitation being lost to evapotranspiration relative to its contribution to Colorado River flow—a trend that is expected to continue as the region warms.[28,51]

Without extensive adaptation, which is challenging because human systems have developed under the historical water cycle patterns (KM 4.2), there is *high confidence* and it is *likely* that these dynamics will further stress existing water supply–demand imbalances. Water supply imbalances primarily refer to the over-allocation of surface water supplies in the region's major rivers, such as the Colorado and Rio Grande, due to committing more water to what are legally known as "beneficial uses" than is currently available. Concurrently, longitudinal studies and climate models suggest that there is *high confidence* that increased flooding will occur due to more intense precipitation events, such as those caused by atmospheric rivers,[71,72] in the region's future.

There is *medium confidence* that flexible and adaptive approaches to water management have the potential to address changing climate risks and mitigate the impacts on people, the environment, and the economy (KM 4.3). While there are abundant examples of such approaches from around the world and in multiple water-use sectors, assessments of the feasibility of these examples in the Southwest are lacking.

Key Message 28.2

Adaptation Efforts Increase to Address Accelerating Impacts to the Region's Coast and Ocean

Description of Evidence Base

Recent research and observed events demonstrate that marine heatwave events will continue and increase in frequency alongside other stressors, impacting marine-resource dependent communities.[35,95] Marine heatwaves and century-scale sea surface temperature warming trends near the coast of California have been attributed to human influence on climate.[385] Adverse impacts to aquaculture and wild-capture fisheries have already been observed and are projected to worsen. Impacts are connected to the degradation of marine ecosystems from not only temperature effects but also ocean acidification, hypoxia, and harmful algal blooms. And while there is extensive literature on the California Current ecosystem and wild-capture fisheries, there are fewer studies on the long-term effects of extreme events and California aquaculture, and thus higher uncertainty.

Sea level rise impacts have been extensively modeled and compared with observed flooding. The most recent lines of evidence are synthesized with a large body of relevant literature included in the 2022 Interagency Task Force report on sea level rise[7] and the Intergovernmental Panel on Climate Change Sixth Assessment Report from Working Group I.[95]

The authors focused on findings on the impacts from sea level rise, which centered around new understandings of sea level rise impacts to groundwater and infrastructure and communities. Energy and transportation infrastructure will continue to be impacted by increased flooding. Furthermore, recent studies have shown that climate impacts will disproportionately impact overburdened communities, but additional research specific to California is lacking.

Adaptation for infrastructure and communities has been accelerating in California through state and local governments, as seen through the release of laws, executive orders, and state guidance documents, as well as an increase in state, Tribal, local, and regional vulnerability assessments and adaptation plans. Government planning requirements and guidance for different sectors are increasing. The State of California also invests in downscaled climate science to inform state and local climate decision-making; the state's climate change assessment has been codified in law. Less information on adaptive strategies for fisheries and aquaculture has been released.

Major Uncertainties and Research Gaps

Long-term, compound implications of greater extremes with other stressors and mitigation strategies are less certain. There is less research in California on combined, long-term impacts of marine heatwaves and multi-stressor effects on ecosystems, species, and aquaculture. However, multi-stressor research is advancing,[386] including for the California Current,[387] increasing our mechanistic understanding of climate change effects. Mitigation strategies of nature-based carbon dioxide removal are growing in interest and investment in the US (Ch. 32),[388] including in California. While the emerging evidence suggests that ocean-based solutions, such as seaweed aquaculture carbon sequestration, are not a global "silver bullet" to mitigate carbon emissions, they may provide some local benefits.[133] However, who benefits from such interventions and the impacts to surrounding ecosystems require further investigation to ensure positive outcomes for nature and people.[389,390,391]

There is a lack of research on the impacts of sea level rise on groundwater flooding, as well as the application of those findings to infrastructure and community analyses. These compounding threats have not been included in most adaptation planning to date, which could result in less adaptive solutions being implemented.

As governments and communities begin building adaptation projects, uncertainties about their efficacy remain. There is limited research tracking adaptation implementation, including research identifying potential ramifications, such as displacement of overburdened communities, economic injustices in terms of resources available for adaptation, and methods to ensure communities are part of decision-making for eventual retreat or relocation. Additional work could help identify how existing funding tools can support adaptation and resilience efforts and how to develop a more robust understanding of adaptation costs and benefits.

Description of Confidence and Likelihood

There is *high confidence* that climate change will increase marine heatwaves and harmful algal blooms (HABs), resulting in impacts to coastal ecosystems and economies. There is *very high confidence* and it is *very likely* that marine heatwave frequency, intensity, and extent will increase. Laufkötter et al. (2020)[385] found that heatwaves have already increased twentyfold because of human-caused global warming and that the probability of occurrences increases in frequency under progressively warmer scenarios. Linkages between HABs and thermal conditions of the oceans have been demonstrated, but frequency and extent are linked to climate and non-climate (e.g., runoff) drivers.[392] There is high agreement and evidence of negative impacts to marine ecosystems and resource-dependent communities in the literature, but under moderate to high climate mitigation scenarios, the severity of impacts will depend on adaptative interventions (e.g., nature-based solutions, adoption of ecosystem-based management).

Sea level rise will *likely* cause increased flooding on the Southwest coast, and there is *very high confidence* that those impacts will severely affect infrastructure and communities, with inequities in how these impacts are experienced. The latest climate models and sea level rise projections demonstrate increased confidence in relative sea level rise amounts by 2050. Sweet et al. (2022)[7] state that relative sea level for the entire contiguous US coastline is expected to rise, on average, as much over the next 40 years (2020–2050) as it has over the last 100 years (1920–2020; 0.82–0.98 feet). Furthermore, by 2050 the expected relative sea level will impact tide and storm surge, leading to major and moderate high tide flood events occurring as frequently as minor high tide flood events occurred in 2022, which will impact infrastructure, communities, and ecosystems.[7]

Given the State of California's progress and leadership on climate science and adaptation planning for sea level rise, there is *high confidence* that adaptation planning and implementation will continue. As evidence, the state's fiscal year 2021–2022 budget included $4 billion (in 2022 dollars) for climate resilience programs, with other new climate resilience programs created in fiscal year 2022–2023. State agencies continue to release adaptation planning guidance (e.g., State Agency Sea Level Rise Action Plan 2022;[393] Extreme Heat Action Plan 2022;[394] State Adaptation Strategy 2021[395]) and new funding programs (e.g., Adaptation Planning Grant Program 2022;[396] Transportation Climate Adaptation Planning Grants 2022;[397] Local Transportation Infrastructure Climate Adaptation Project [LTCAP] Program 2022;[398] Regional Resilience Planning and Implementation Grant Program 2022[399]). There is limited to no inclusion of aquaculture in California state climate planning (e.g., Lester et al. 2022[400]), and comparatively less coverage overall in the scientific literature compared to wild capture and agriculture,[401] and thus there is *high confidence* that climate planning and adaptation solutions for aquaculture are less clear.

Key Message 28.3

Increasing Challenges Confront Food and Fiber Production in the Southwest

Description of Evidence Base

Temperature and precipitation data clearly show that this century has been warmer and drier than the last.[50,381,402] This drying and warming trend is already resulting in measurable impacts on rangeland forage production,[403] dryland agriculture,[404] and irrigated crop yields. A substantial literature exists showing the impact of climate change on livestock production through changes in food quantity and quality, pests and disease, and animal health and well-being.[405] Evidence shows that climate is already affecting the distribution of livestock agriculture in the east of region. The Southern Plains (in New Mexico) and Central Plains (in Colorado) saw large decreases in cow numbers in the 2011–2014 drought.[406] Increasingly the Southwest's agricultural economy relies on crop production, but research anticipates downward trends in the production of numerous high-value crops in California[169] and reduced or less reliable supply of irrigation water that supports crop production throughout the region. Numerous examples of adaptation strategies exist, such as improved irrigation technologies, soil protection strategies, and shifts to Indigenous practices and crops, although there are barriers that inhibit widespread adoption of many of these practices.

Major Uncertainties and Research Gaps

Southwestern food and fiber production is diverse, spanning rangeland livestock systems, irrigated croplands and orchards, dryland, and Indigenous farming. Each of these systems is nested within local, regional, and international contexts that can exacerbate or alleviate vulnerability to climate change. This diversity, combined with factors other than climate change (e.g., global pandemics, inflation, supply chains, access to financial support) contribute to the complexity of assessing the impacts of climate change on southwestern agriculture. There are therefore research gaps and some uncertainty on how the adaptation options described in the agronomic and range management literature can be applied in the real world.

Research gaps remain in our understanding of not only the biophysical and socioeconomic capacity to support change in southwestern agrosystems but also the will of farmers and policymakers to change the type of crops that are grown. For livestock producers who rely on forage from public lands, there is uncertainty about how climate change will affect the number of animals the land can support and how possible reductions in stocking rate will affect the viability of ranches and ranching-dependent communities.

Description of Confidence and Likelihood

There is *high confidence* that continuing drought and water scarcity will make it more difficult to raise food and fiber in the Southwest without major shifts to new strategies and technologies. Climate models agree that the Southwest will continue to warm. This impacts the thermal tolerance and chilling requirements for economically important crops. There are multiple indicators that the Southwest is undergoing aridification; as a consequence, it is expected that there will be less available water for irrigated agriculture in the future.

Given substantive evidence in the literature, there is *high confidence*, and it is *likely*, that extreme heat events will continue to occur and are expected to worsen in intensity and increase in frequency in the 21st century.[167] Extreme heat reduces crop quality and yield[181,403] and affects livestock productivity (and in some cases survival), resulting in economic impacts.[197,198,405] USDA Risk Management Agency indemnities data from 1989 to 2021 show that heat events are already driving crop production losses across the region.

There is a growing literature that advocates for greater inclusion of Indigenous Knowledge for informing adaptation solutions in Southwest agriculture. There is *medium confidence* that Indigenous Knowledge, along with technological innovation, has the potential to inform sustainable agricultural practice regionwide, as well as increasing Indigenous food sovereignty, because there are few studies to date that demonstrate how Indigenous Knowledge can be drawn on to adapt larger acreages or commercial operations to climate change. It is also evident in the literature that technical innovations (e.g., agrivoltaics, internet of things) have yet to become more widely adopted or applied to larger acreage operations.

Key Message 28.4

Climate Change Compromises Human Health and Reshapes Demographics

Description of Evidence Base

Strong evidence and good agreement among multiple sources and lines of evidence show that extreme heat exposures already are leading to heat-associated deaths and illnesses across the region.[228,233,407] Exposures to extreme heat for city dwellers are increasing, partly due to human-caused climate change and partly due to urban-induced warming.[408,409] Regional-scale warming in the Southwest since 1901 exceeds what would be expected from natural variability and is partly attributable to human influence.[3] Climate change has doubled the likelihood of an event capable of producing catastrophic flooding for California, and future increases to this risk are expected due to continued warming.[271,272]

Multiple lines of evidence indicate current and future increases in human exposures and adverse health outcomes to wildfire smoke in the region.[277,410,411] Good agreement exists among models that the intensified arid conditions in the region will result in more dust storms[243] and thus a higher incidence of respiratory ailments, including Valley fever.[246,248]

Evidence supports the need for increased investments in adaptative strategies that support social, physical, and health systems that enhance individual and community resilience to changes in climate, particularly extreme heat.[288,412,413,414,415] Improving public health systems and community infrastructure in the region can reduce the health consequences of climate change.

Major Uncertainties and Research Gaps

Uncertainties exist in the attribution of changes in climate variables to specific health outcomes. The collection of and alignment of more environmental and health data will assist in understanding the long-term nature of how climate change affects specific health outcomes. Detecting direct relationships between climate change impacts and public health outcomes is also made more difficult due to confounding factors related to socioeconomics, vulnerability, exposure assessments, demographic shifts, migration, and community and individual characteristics. Detection and attribution studies are thus vital to the region for addressing multiple public health concerns (e.g., Ebi et al. 2020[30]).

Related uncertainties in how regional changes in climate will affect public health exist due to variability in projections of extreme precipitation; uncertainties in the occurrence and intensity of climate-sensitive exposures that impact human health, including wildfire smoke exposures; and variability in local and regional ozone based on meteorological conditions and emissions-reduction targets achieved.

Uncertainties also exist in projecting climate-related changes to the abundance of vector-borne diseases and associated disruptions. While US rates of chikungunya and Zika dropped[416] with widespread travel restrictions due to COVID-19, issues with West Nile virus (WNV) remain due to the endemic nature of the virus in the region. The most common WNV vector in the region (*Culex quinquefasciatus*) is abundant in urbans areas such as Los Angeles, Albuquerque, and Phoenix,[417] and certain water management structures (e.g., catch basins, storm drains, and retention ponds) provide favorable environments for *Cx. quinquefasciatus* reproduction.[418] There is also uncertainty around how heavy precipitation, as compared to drought conditions, impacts the abundance and distribution of vector-borne diseases connected to human activity and management of water. Transmission of WNV is also projected to shift northward,[419] thus decreasing potential risks of transmission in parts of the Southwest.

Finally, considerable uncertainties exist in how individuals and communities will adapt to the effects of climate change in the region. Model projections of health impacts rarely account for adaptive capacity changes into the future. Improving adaptive capacity involves enhancing infrastructure, technologies, behavior, and the overall health of the population to cope with climate effects.

Description of Confidence and Likelihood

There is *high confidence* that increases in extreme heat, drought, flooding, and wildfire activity are negatively impacting the physical health of Southwest residents. Climate models agree that the Southwest is experiencing higher temperatures and more intense, longer, and more frequent heat events.[3,8,375,420]Extreme heat exposure causes mortality, morbidity, and lost productivity if dangerous exposures occur (KM 15.2).[235,421] Drier conditions lead to a greater risk of wildfires and particulate matter, which adversely affect human respiratory and cardiovascular health when exposed.[265,290,422,423,424]

Climate change is also shaping the demographics of the region by spurring the migration of people to the Southwest, primarily from Central America (*medium confidence*). In 2021, about 13 million people (representing 21.3% of total population) living in the Southwest were foreign born; 21.1% of those foreign born entered the United States in the last 10 years.[425] Decreasing agricultural productivity, increasing levels of food insecurity, and adverse climate effects are among the main reasons why people emigrate from the Northern Triangle (Guatemala, Honduras, and El Salvador) to the US (KM 17.2).[32,279] About 43% of immigrants apprehended at the Southwest border in 2019 originated from the Northern Triangle.[278]

Individuals particularly vulnerable to increasing climate change impacts include older adults, outdoor workers, and people with low income (*high confidence*). Wildfires and the related smoke are affecting a higher number of people, with strong evidence pointing to the most vulnerable populations being at greatest risk.[426] Strong evidence further connects rising particulate matter levels to higher risk in already-vulnerable populations, including individuals with low income, Indigenous Peoples, pregnant people, children, and outdoor workers.[427,428,429,430,431] It has been well documented that extreme heat disproportionately impacts the health of the most vulnerable populations in the region, including the unhoused,[227,228,229] outdoor workers, and migrant farmworkers,[230,231,232,233] as well as people with low income,[8,234] older adults,[235] and pregnant people and babies (particularly with air pollution co-exposures).[237,238,239,240]

There is *high confidence* that local, state, and federal initiatives can respond to these climatic and demographic changes by helping people and communities become healthier and more resilient. There is strong evidence that increasing adaptive capacity and resilience across communities, especially the most vulnerable, will reduce the human health impacts of climate change.[432] The relative importance of various adaptive strategies will differ across spatial and temporal scales, climatology, and social and behavioral contexts. Improving public health systems, overall health, community infrastructure, and education can reduce health risks that are being exacerbated in the Southwest due to climate change, as well as many health risks in general.[431]

Key Message 28.5

Changes in Wildfire Patterns Pose Challenges for Southwest Residents and Ecosystems

Description of Evidence Base

Changing wildfire dynamics include increases in wildfire size and severity and changing and lengthening fire seasons.[18,303,433,434] Extensive research has found that climate change is linked to increases in extreme fire weather,[18] wildfire activity,[20,303,326] wildfire severity,[17,19,21,434] and acreage burned annually.[302] Unprecedented high-severity fires have driven ecosystem conversions in many parts of the region.[294,311] Recent climate-induced aridification, including loss of snowpack, has also reduced postfire tree seedling and shrub establishment, limiting ecosystem recovery.[313,314,315]

Projections suggest that future fire activity will continue to degrade ecosystems and alter their structure and function.[294,298,319] Increased fire activity,[320,321,322] further warming and drying that stress tree seedlings, and model projections of stand-replacing fires at the forest/non-forest boundary in the western US[316] have raised the possibility of shifts in species composition or vegetation type.[294,317] These projections suggest high variability in ecosystem responses depending on interactions between vegetation type, moisture stress, disturbance regimes, and human alterations.[314,319,435,436,437,438]

Increasing wildfire risk poses threats to lives and livelihoods in the region. Wildfire and accompanying smoke have led to fatalities caused by the fires themselves,[304,327] by smoke from wildfires,[328] and by debris flows that occur when heavy rains fall on recently burned slopes.[330] Even if not fatal, wildfires have been linked to declines in physical health[265,328,439] and mental health.[268] Frontline communities, including low-income groups and populations of color, are especially vulnerable to these impacts.[231,338] Exposure of people in the Southwest to wildfire risk is also increasing due to population growth in wildland–urban interface areas near fire-prone forests, shrublands, and grasslands.[331,332,333] Economic costs to individual households come from structures burned and increased insurance and healthcare costs.[440,441] Further costs come from income lost due to fires that affect energy, agriculture, and tourism.[340,341,342,353]

Adaptation strategies include reduction in tree density and wildland fuels[299,355,358,359] that can reduce the size and severity of fires when they occur. Integration of Indigenous burning practices with contemporary forest management can mitigate wildfire risk as well.[296] Risk is expected to be reduced through public safety power shutoffs initiated by electric utilities when weather conditions suggest wildfire danger is especially high.[370]

Major Uncertainties and Research Gaps

The short-term likelihood of increasing wildfire risks and impacts is very high. What is less clear is the extent to which adaptation strategies such as increasing fuel-reduction treatments and adoption of climate-adapted silviculture will be able to mitigate those impacts. As yet, there has been no reliable way to quantify the degree to which increases in fire area and severity are due to climate change versus past management, non-native species invasions, urbanization, or other factors. To restore forest resilience (KM 7.3), the rate of thinning and fuel reduction needs to be greatly increased, and it is not known whether resources will be available to achieve such intensified management. Fire ecologists point to the need for increasing use of prescribed burning to reduce fuel loads, but it is not certain how much this increase can be achieved, considering the increasing risk of fire escape and public unease about the use of fire as a management tool.[361] Geographic factors, forest policies, and public attitudes toward forest management can constrain the rate at which risk-reduction actions can be implemented. Similarly, long-term attitudes toward public safety power shutoffs, restrictions on homebuilding in fire-prone landscapes, and other risk-reduction policies are uncertain.

Description of Confidence and Likelihood

There is *high confidence* that the Southwest region is experiencing unprecedented wildfire occurrence and that this change is linked to climate change. Contributing causes include land management policies that have led to high tree densities that increase fuel for fires,[295,318] climate-mediated events such as insect and tree disease outbreaks (Box 7.1),[319] and increased human population at the forest's edge,[331] all of which interact with climate change in ways that increase wildfire risk and occurrence.[18,21]

There is *high confidence* that fires in the region have become larger and more severe. Increased temperatures and changes to precipitation have combined to produce an increase in vapor pressure deficit.[333] This, in conjunction with episodes of climatic extremes such as droughts and heatwaves, means it is *very likely* that these trends will continue in the region's forests.[319,320,321,322] However, there is less certainty about future trends in non-forested areas because of high year-to-year variability in production of the grasses that fuel wildfires,[324] with model projections suggesting that climate impacts on plant growth will vary across the region.[325]

There is *high confidence* that severe wildfires are placing people, economies, ecosystems, and water resources at risk, and it is *very likely* that severe wildfires will continue, partially because of climate change impacts. There is consensus among studies from climate models that the Southwest will continue to warm, and there are multiple indicators that the region is becoming more arid, increasing wildfire risk. There are many indicators of costs to human lives, health, and livelihoods due to wildfire, and as the risk of catastrophic wildfire increases, so do those costs.

There is *medium confidence* that adaptation pathways will reduce wildfire risk and promote ecosystem restoration through forest management and other adaptations such as the application of Indigenous Knowledges. While the adaptation opportunities are known, it is less clear whether society will have the capacity to embrace those opportunities.

References

1. U.S. Census Bureau. 2010: State Area Measurements and Internal Point Coordinates. U.S. Department of Commerce, U.S. Census Bureau. https://www.census.gov/geographies/reference-files/2010/geo/state-area.html

2. NCEI, 2022: U.S. Billion-Dollar Weather and Climate Disasters. National Oceanic and Atmospheric Administration, National Environmental Satellite, Data, and Information Service, National Centers for Environmental Information. https://www.ncei.noaa.gov/access/billions/

3. Vose, R.S., D.R. Easterling, K.E. Kunkel, A.N. LeGrande, and M.F. Wehner, 2017: Ch. 6. Temperature changes in the United States. In: *Climate Science Special Report: Fourth National Climate Assessment, Volume I*. Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock, Eds. U.S. Global Change Research Program, Washington, DC, USA, 185–206. https://doi.org/10.7930/j0n29v45

4. Mote, P.W., S. Li, D.P. Lettenmaier, M. Xiao, and R. Engel, 2018: Dramatic declines in snowpack in the western US. *Npj Climate and Atmospheric Science*, **1** (1), 1–6. https://doi.org/10.1038/s41612-018-0012-1

5. Siirila-Woodburn, E.R., A.M. Rhoades, B.J. Hatchett, L.S. Huning, J. Szinai, C. Tague, P.S. Nico, D.R. Feldman, A.D. Jones, W.D. Collins, and L. Kaatz, 2021: A low-to-no snow future and its impacts on water resources in the western United States. *Nature Reviews Earth & Environment*, **2** (11), 800–819. https://doi.org/10.1038/s43017-021-00219-y

6. Uzun, S., T. Tanir, G.d.A. Coelho, A.d. Souza de Lima, F. Cassalho, and C.M. Ferreira, 2021: Changes in snowmelt runoff timing in the contiguous United States. *Hydrological Processes*, **35** (11), e14430. https://doi.org/10.1002/hyp.14430

7. Sweet, W.V., B.D. Hamlington, R.E. Kopp, C.P. Weaver, P.L. Barnard, D. Bekaert, W. Brooks, M. Craghan, G. Dusek, T. Frederikse, G. Garner, A.S. Genz, J.P. Krasting, E. Larour, D. Marcy, J.J. Marra, J. Obeysekera, M. Osler, M. Pendleton, D. Roman, L. Schmied, W. Veatch, K.D. White, and C. Zuzak, 2022: Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities Along U.S. Coastlines. NOAA Technical Report NOS 01. National Oceanic and Atmospheric Administration, National Ocean Service, Silver Spring, MD, 111 pp. https://oceanservice.noaa.gov/hazards/sealevelrise/sealevelrise-tech-report-sections.html

8. Gabbe, C.J. and G. Pierce, 2020: Extreme heat vulnerability of subsidized housing residents in California. *Housing Policy Debate*, **30** (5), 843–860. https://doi.org/10.1080/10511482.2020.1768574

9. Knutson, T.R. and J.J. Ploshay, 2016: Detection of anthropogenic influence on a summertime heat stress index. *Climatic Change*, **138** (1), 25–39. https://doi.org/10.1007/s10584-016-1708-z

10. Li, C., X. Zhang, F. Zwiers, Y. Fang, and A.M. Michalak, 2017: Recent very hot summers in northern hemispheric land areas measured by wet bulb globe temperature will be the norm within 20 years. *Earth's Future*, **5** (12), 1203–1216. https://doi.org/10.1002/2017ef000639

11. Vicedo-Cabrera, A.M., N. Scovronick, F. Sera, D. Royé, R. Schneider, A. Tobias, C. Astrom, Y. Guo, Y. Honda, D.M. Hondula, R. Abrutzky, S. Tong, M.d.S.Z.S. Coelho, P.H.N. Saldiva, E. Lavigne, P.M. Correa, N.V. Ortega, H. Kan, S. Osorio, J. Kyselý, A. Urban, H. Orru, E. Indermitte, J.J.K. Jaakkola, N. Ryti, M. Pascal, A. Schneider, K. Katsouyanni, E. Samoli, F. Mayvaneh, A. Entezari, P. Goodman, A. Zeka, P. Michelozzi, F. de'Donato, M. Hashizume, B. Alahmad, M.H. Diaz, C.D.L.C. Valencia, A. Overcenco, D. Houthuijs, C. Ameling, S. Rao, F. Di Ruscio, G. Carrasco-Escobar, X. Seposo, S. Silva, J. Madureira, I.H. Holobaca, S. Fratianni, F. Acquaotta, H. Kim, W. Lee, C. Iniguez, B. Forsberg, M.S. Ragettli, Y.L.L. Guo, B.Y. Chen, S. Li, B. Armstrong, A. Aleman, A. Zanobetti, J. Schwartz, T.N. Dang, D.V. Dung, N. Gillett, A. Haines, M. Mengel, V. Huber, and A. Gasparrini, 2021: The burden of heat-related mortality attributable to recent human-induced climate change. *Nature Climate Change*, **11** (6), 492–500. https://doi.org/10.1038/s41558-021-01058-x

12. Miller, K., A. Milman, and M. Kiparsky, 2021: Introduction to the Special Collection: Institutional dimensions of groundwater recharge. *Case Studies in the Environment*, **5** (1). https://doi.org/10.1525/cse.2021.1245648

13. Milly, P.C.D. and K.A. Dunne, 2016: Potential evapotranspiration and continental drying. *Nature Climate Change*, **6**, 946–969. https://doi.org/10.1038/nclimate3046

14. Overpeck, J.T. and B. Udall, 2020: Climate change and the aridification of North America. *Proceedings of the National Academy of Sciences of the United States of America*, **117** (22), 11856–11858. https://doi.org/10.1073/pnas.2006323117

15. Talsma, C.J., K.E. Bennett, and V.V. Vesselinov, 2022: Characterizing drought behavior in the Colorado River Basin using unsupervised machine learning. *Earth and Space Science*, **9** (5), e2021EA002086. https://doi.org/10.1029/2021ea002086

16. Xiao, M., B. Udall, and D.P. Lettenmaier, 2018: On the causes of declining Colorado River streamflows. *Water Resources Research*, **54** (9), 6739–6756. https://doi.org/10.1029/2018wr023153

17. Duane, A., M. Castellnou, and L. Brotons, 2021: Towards a comprehensive look at global drivers of novel extreme wildfire events. *Climatic Change*, **165** (3), 43. https://doi.org/10.1007/s10584-021-03066-4

18. Goss, M., D.L. Swain, J.T. Abatzoglou, A. Sarhadi, C.A. Kolden, A.P. Williams, and N.S. Diffenbaugh, 2020: Climate change is increasing the likelihood of extreme autumn wildfire conditions across California. *Environmental Research Letters*, **15** (9), 094016. https://doi.org/10.1088/1748-9326/ab83a7

19. Mueller, S.E., A.E. Thode, E.Q. Margolis, L.L. Yocom, J.D. Young, and J.M. Iniguez, 2020: Climate relationships with increasing wildfire in the southwestern US from 1984 to 2015. *Forest Ecology and Management*, **460**, 117861. https://doi.org/10.1016/j.foreco.2019.117861

20. Swain, D.L., 2021: A shorter, sharper rainy season amplifies California wildfire risk. *Geophysical Research Letters*, **48** (5), e2021GL092843. https://doi.org/10.1029/2021gl092843

21. Williams, A.P., J.T. Abatzoglou, A. Gershunov, J. Guzman-Morales, D.A. Bishop, J.K. Balch, and D.P. Lettenmaier, 2019: Observed impacts of anthropogenic climate change on wildfire in California. *Earth's Future*, **7** (8), 892–910. https://doi.org/10.1029/2019ef001210

22. BEA, 2022: Gross Domestic Product by State and Personal Income by State, 2nd Quarter 2022. BEA 22–48. U.S. Department of Commerce, Bureau of Economic Analysis. https://www.bea.gov/data/gdp/gdp-state

23. Bureau of Indian Affairs, 2017: Indian entities recognized and eligible to receive services from the United States Bureau of Indian Affairs. *Federal Register*, **82** (10), 4915–4920. https://www.federalregister.gov/documents/2017/01/17/2017-00912/indian-entities-recognized-and-eligible-to-receive-services-from-the-united-states-bureau-of-indian

24. CRS, 2020: Federal Land Ownership: Overview and Data. CRS Report R42346. Congressional Research Service. https://crsreports.congress.gov/product/pdf/r/r42346

25. Gonzalez, P., G.M. Garfin, D.D. Breshears, K.M. Brooks, H.E. Brown, E.H. Elias, A. Gunasekara, N. Huntly, J.K. Maldonado, N.J. Mantua, H.G. Margolis, S. McAfee, B.R. Middleton, and B.H. Udall, 2018: Ch. 25. Southwest. In: *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*. Reidmiller, D.R., C.W. Avery, D. Easterling, K. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart, Eds. U.S. Global Change Research Program, Washington, DC, USA, 1101–1184. https://doi.org/10.7930/nca4.2018.ch25

26. Hoerling, M., J. Eischeid, X. Quan, and A. Badger, 2019: Causes for the century-long decline in Colorado River flow. *Journal of Climate*, **32** (23), 8181–8203. https://doi.org/10.1175/jcli-d-19-0207.1

27. Lukas, J.J. and E.A. Payton, 2020: Colorado River Basin Climate and Hydrology: State of the Science. Western Water Assessment. University of Colorado Boulder, Cooperative Institute for Research in Environmental Sciences, Boulder, CO. https://doi.org/10.25810/3hcv-w477

28. Udall, B. and J. Overpeck, 2017: The twenty-first century Colorado River hot drought and implications for the future. *Water Resources Research*, **53** (3), 2404–2418. https://doi.org/10.1002/2016wr019638

29. Steele, C., J. Reyes, E. Elias, S. Aney, and A. Rango, 2018: Cascading impacts of climate change on southwestern US cropland agriculture. *Climatic Change*, **148** (3), 437–450. https://doi.org/10.1007/s10584-018-2220-4

30. Ebi, K.L., C. Åström, C.J. Boyer, L.J. Harrington, J.J. Hess, Y. Honda, E. Kazura, R.F. Stuart-Smith, and F.E.L. Otto, 2020: Using detection and attribution to quantify how climate change is affecting health. *Health Affairs*, **39** (12), 2168–2174. https://doi.org/10.1377/hlthaff.2020.01004

31. Hait, A.W., 2021: Growth in the Desert Southwest Mirrors the Nation in Some Economic Sectors but Is Quite Different in Others. U.S. Census Bureau. https://www.census.gov/library/stories/2021/09/business-growth-in-desert-southwest-more-than-twice-national-average.html

32. Spencer, N. and M.-A. Urquhart, 2018: Hurricane strikes and migration: Evidence from storms in Central America and the Caribbean. *Weather, Climate, and Society*, **10** (3), 569–577. https://doi.org/10.1175/wcas-d-17-0057.1

33. Newell, J.P., B. Goldstein, and A. Foster, 2019: A 40-year review of food-energy-water nexus literature and its application to the urban scale. *Environmental Research Letters*, **14** (7). https://doi.org/10.1088/1748-9326/ab0767

34. Opejin, A.K., R.M. Aggarwal, D.D. White, J.L. Jones, R. Maciejewski, G. Mascaro, and H.S. Sarjoughian, 2020: A bibliometric analysis of food-energy-water nexus literature. *Sustainability*, **12** (3), 1112. https://doi.org/10.3390/su12031112

35. IPCC, 2022: *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Pörtner, H.-O., D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, and B. Rama, Eds. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp. https://doi.org/10.1017/9781009325844

36. Jones, J.L. and D.D. White, 2022: Understanding barriers to collaborative governance for the food-energy-water nexus: The case of Phoenix, Arizona. *Environmental Science and Policy*, **127**, 111–119. https://doi.org/10.1016/j.envsci.2021.10.025

37. Koebele, E.A., 2020: Cross-coalition coordination in collaborative environmental governance processes. *Policy Studies Journal*, **48** (3), 727–753. https://doi.org/10.1111/psj.12306

38. Sullivan, A., D.D. White, and M. Hanemann, 2019: Designing collaborative governance: Insights from the drought contingency planning process for the lower Colorado River Basin. *Environmental Science and Policy*, **91**, 39–49. https://doi.org/10.1016/j.envsci.2018.10.011

39. The California Climate Crisis Act. Assembly Bill No. 1279, State of California, September 16, 2022. https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202120220AB1279

40. State of California, 2018: Executive Order B-55-18: To Achieve Carbon Neutrality. State of California, Executive Department. https://www.ca.gov/archive/gov39/wp-content/uploads/2018/09/9.10.18-Executive-Order.pdf

41. CARB, 2022: Scoping Plan for Achieving Carbon Neutrality. California Air Resources Board. https://ww2.arb.ca.gov/sites/default/files/2022-12/2022-sp.pdf

42. State of California, 2021: California Climate Commitment: Biggest Climate Investment in History. State of California, 2 pp. https://www.gov.ca.gov/wp-content/uploads/2022/06/california-climate-commitment-.pdf

43. Climate Action Plan to Reduce Pollution. HB19-1261, State of Colorado, 2019. https://leg.colorado.gov/bills/hb19-1261

44. State of New Mexico, 2019: Executive Order 2019-003: Executive Order on Addressing Climate Change and Energy Waste Prevention. State of New Mexico, Executive Office, 4 pp. https://www.governor.state.nm.us/wp-content/uploads/2019/01/EO_2019-003.pdf

45. Gangopadhyay, S., C.A. Woodhouse, G.J. McCabe, C.C. Routson, and D.M. Meko, 2022: Tree rings reveal unmatched 2nd century drought in the Colorado River Basin. *Geophysical Research Letters*, **49** (11), e2022GL098781. https://doi.org/10.1029/2022gl098781

46. Meko, D.M., C.A. Woodhouse, and A.G. Winitsky, 2022: Tree-ring perspectives on the Colorado River: Looking back and moving forward. *JAWRA Journal of the American Water Resources Association*, **58** (5), 604–621. https://doi.org/10.1111/1752-1688.12989

47. Albano, C.M., J.T. Abatzoglou, D.J. McEvoy, J.L. Huntington, C.G. Morton, M.D. Dettinger, and T.J. Ott, 2022: A Multidataset assessment of climatic drivers and uncertainties of recent trends in evaporative demand across the continental United States. *Journal of Hydrometeorology*, **23** (4), 505–519. https://doi.org/10.1175/jhm-d-21-0163.1

48. Lehner, F., E.R. Wahl, A.W. Wood, D.B. Blatchford, and D. Llewellyn, 2017: Assessing recent declines in Upper Rio Grande runoff efficiency from a paleoclimate perspective. *Geophysical Research Letters*, **44** (9), 4124–4133. https://doi.org/10.1002/2017gl073253

49. Milly, P.C.D. and K.A. Dunne, 2020: Colorado River flow dwindles as warming-driven loss of reflective snow energizes evaporation. *Science*, **367** (6483), 1252–1255. https://doi.org/10.1126/science.aay9187

50. Su, L., Q. Cao, M. Xiao, D.M. Mocko, M. Barlage, D. Li, C.D. Peters-Lidard, and D.P. Lettenmaier, 2021: Drought variability over the conterminous United States for the past century. *Journal of Hydrometeorology*, **22** (5), 1153–1168. https://doi.org/10.1175/jhm-d-20-0158.1

51. Williams, A.P., B.I. Cook, and J.E. Smerdon, 2022: Rapid intensification of the emerging southwestern North American megadrought in 2020–2021. *Nature Climate Change*, **12** (3), 232–234. https://doi.org/10.1038/s41558-022-01290-z

52. Lynn, E., A. Cuthbertson, M. He, J.P. Vasquez, M.L. Anderson, P. Coombe, J.T. Abatzoglou, and B.J. Hatchett, 2020: Technical note: Precipitation-phase partitioning at landscape scales to regional scales. *Hydrology and Earth System Sciences*, **24** (11), 5317–5328. https://doi.org/10.5194/hess-24-5317-2020

53. Skiles, S.M.K., M. Flanner, J.M. Cook, M. Dumont, and T.H. Painter, 2018: Radiative forcing by light-absorbing particles in snow. *Nature Climate Change*, **8** (11), 964–971. https://doi.org/10.1038/s41558-018-0296-5

54. Livneh, B. and A.M. Badger, 2020: Drought less predictable under declining future snowpack. *Nature Climate Change*, **10** (5), 452–458. https://doi.org/10.1038/s41558-020-0754-8

55. Walton, D.B., A. Hall, N. Berg, M. Schwartz, and F. Sun, 2017: Incorporating snow albedo feedback into downscaled temperature and snow cover projections for California's Sierra Nevada. *Journal of Climate*, **30** (4), 1417–1438. https://doi.org/10.1175/jcli-d-16-0168.1

56. Gordon, B.L., P.D. Brooks, S.A. Krogh, G.F.S. Boisrame, R.W.H. Carroll, J.P. McNamara, and A.A. Harpold, 2022: Why does snowmelt-driven streamflow response to warming vary? A data-driven review and predictive framework. *Environmental Research Letters*, **17** (5), 053004. https://doi.org/10.1088/1748-9326/ac64b4

57. Pierce, D.W., 2023: LOCA Statistical Downscaling. University of San Diego, Scripps Institution of Oceanography. https://loca.ucsd.edu/

58. Vano, J., J. Hamman, E. Gutmann, A. Wood, N. Mizukami, M. Clark, D.W. Pierce, D.R. Cayan, C. Wobus, K. Nowak, and J. Arnold, 2020: Comparing Downscaled LOCA and BCSD CMIP5 Climate and Hydrology Projections: Release of Downscaled LOCA CMIP5 Hydrology. Bureau of Reclamation, Livermore, CA, 96 pp. https://gdo-dcp.ucllnl.org/downscaled_cmip_projections/techmemo/LOCA_BCSD_hydrology_tech_memo.pdf

59. Woodhouse, C.A. and G.T. Pederson, 2018: Investigating runoff efficiency in upper Colorado River streamflow over past centuries. *Water Resources Research*, **54** (1), 286–300. https://doi.org/10.1002/2017wr021663

60. Berg, A. and J. Sheffield, 2018: Climate change and drought: The soil moisture perspective. *Current Climate Change Reports*, **4** (2), 180–191. https://doi.org/10.1007/s40641-018-0095-0

61. Null, S.E. and W.A. Wurtsbaugh, 2020: Ch. 1. Water development, consumptive water uses, and Great Salt Lake. In: *Great Salt Lake Biology: A Terminal Lake in a Time of Change*. Baxter, B.K. and J.K. Butler, Eds. Springer, Cham, Switzerland, 1–21. https://doi.org/10.1007/978-3-030-40352-2_1

62. Mankin, J.S., I. Simpson, A. Hoell, R. Fu, J. Lisonbee, A. Sheffield, and D. Barrie, 2021: NOAA Drought Task Force Report on the 2020–2021 Southwestern U.S. Drought. National Oceanic and Atmospheric Administration Drought Task Force, Modeling, Analysis, Predictions, and Projections Program, and National Integrated Drought Information System. https://www.drought.gov/documents/noaa-drought-task-force-report-2020-2021-southwestern-us-drought

63. Al Atawneh, D., N. Cartwright, and E. Bertone, 2021: Climate change and its impact on the projected values of groundwater recharge: A review. *Journal of Hydrology*, **601**, 126602. https://doi.org/10.1016/j.jhydrol.2021.126602

64. Meixner, T., A.H. Manning, D.A. Stonestrom, D.M. Allen, H. Ajami, K.W. Blasch, A.E. Brookfield, C.L. Castro, J.F. Clark, D.J. Gochis, A.L. Flint, K.L. Neff, R. Niraula, M. Rodell, B.R. Scanlon, K. Singha, and M.A. Walvoord, 2016: Implications of projected climate change for groundwater recharge in the western United States. *Journal of Hydrology*, **534**, 124–138. https://doi.org/10.1016/j.jhydrol.2015.12.027

65. Russo, T.A. and U. Lall, 2017: Depletion and response of deep groundwater to climate-induced pumping variability. *Nature Geoscience*, **10** (2), 105–108. https://doi.org/10.1038/ngeo2883

66. Sheng, Z., 2013: Impacts of groundwater pumping and climate variability on groundwater availability in the Rio Grande Basin. *Ecosphere*, **4** (1), 5. https://doi.org/10.1890/es12-00270.1

67. Lund, J., J. Medellin-Azuara, J. Durand, and K. Stone, 2018: Lessons from California's 2012–2016 drought. *Journal of Water Resources Planning and Management*, **144** (10), 04018067. https://doi.org/10.1061/(asce)wr.1943-5452.0000984

68. Davenport, F.V., J.E. Herrera-Estrada, M. Burke, and N.S. Diffenbaugh, 2020: Flood size increases nonlinearly across the western United States in response to lower snow-precipitation ratios. *Water Resources Research*, **56** (1), e2019WR025571. https://doi.org/10.1029/2019wr025571

69. Li, D., D.P. Lettenmaier, S.A. Margulis, and K. Andreadis, 2019: The role of rain-on-snow in flooding over the conterminous United States. *Water Resources Research*, **55** (11), 8492–8513. https://doi.org/10.1029/2019wr024950

70. Huang, H., M.R. Fischella, Y. Liu, Z. Ban, J.v. Fayne, D. Li, K.C. Cavanaugh, and D.P. Lettenmaier, 2022: Changes in mechanisms and characteristics of western U.S. floods over the last sixty years. *Geophysical Research Letters*, **49** (3). https://doi.org/10.1029/2021gl097022

71. Albano, C.M., M.D. Dettinger, and A.A. Harpold, 2020: Patterns and drivers of atmospheric river precipitation and hydrologic impacts across the western United States. *Journal of Hydrometeorology*, **21** (1), 143–159. https://doi.org/10.1175/jhm-d-19-0119.1

72. Gershunov, A., T. Shulgina, R.E.S. Clemesha, K. Guirguis, D.W. Pierce, M.D. Dettinger, D.A. Lavers, D.R. Cayan, S.D. Polade, J. Kalansky, and F.M. Ralph, 2019: Precipitation regime change in western North America: The role of atmospheric rivers. *Scientific Reports*, **9** (1), 9944. https://doi.org/10.1038/s41598-019-46169-w

73. Pierce, D.W., J.F. Kalansky, and D.R. Cayan, 2018: Climate, Drought, and Sea Level Rise Scenarios for the Fourth California Climate Assessment. California's Fourth Climate Change Assessment. Publication Number: CNRA-CEC-2018-006. California Energy Commission. https://www.energy.ca.gov/sites/default/files/2019-11/projections_ccca4-cec-2018-006_ada.pdf

74. Wang, J., H. Yin, E. Reyes, T. Smith, and F. Chung, 2018: Mean and Extreme Climate Change Impacts on the State Water Project. California's Fourth Climate Change Assessment. Publication Number: CCCA4-EXT-2018-004. California Energy Commission. https://www.energy.ca.gov/sites/default/files/2019-12/water_ccca4-ext-2018-004_ada.pdf

75. Hatcher, S.M., C. Agnew-Brune, M. Anderson, L.D. Zambrano, C.E. Rose, M.A. Jim, A. Baugher, G.S. Liu, S.v. Patel, M.E. Evans, T. Pindyck, C.L. Dubray, J.J. Rainey, J. Chen, C. Sadowski, K. Winglee, A. Penman-Aguilar, A. Dixit, E. Claw, and J. McCollum, 2020: COVID-19 among American Indian and Alaska Native persons—23 states, January 31–July 3, 2020. *Morbidity and Mortality Weekly Report*, **69** (34). https://doi.org/10.15585/mmwr.mm6934e1

76. ASCE, 2017: The Economic Benefits of Investing in Water Infrastructure: How a Failure to Act Would Affect the US Economic Recovery. American Society of Civil Engineers. www.downstreamstrategies.com

77. Tanana, H., J. Combs, and A. Hoss, 2021: Water is life: Law, systemic racism, and water security in Indian Country. *Health Security*, **19** (1), 78–82. https://doi.org/10.1089/hs.2021.0034

78. Yang, Y.C.E., K. Son, F. Hung, and V. Tidwell, 2020: Impact of climate change on adaptive management decisions in the face of water scarcity. *Journal of Hydrology*, **588**, 125015. https://doi.org/10.1016/j.jhydrol.2020.125015

79. Sanders, B.F., J.E. Schubert, D.T. Kahl, K.J. Mach, D. Brady, A. AghaKouchak, F. Forman, R.A. Matthew, N. Ulibarri, and S.J. Davis, 2023: Large and inequitable flood risks in Los Angeles, California. *Nature Sustainability*, **6** (1), 47–57. https://doi.org/10.1038/s41893-022-00977-7

80. Schaider, L.A., L. Swetschinski, C. Campbell, and R.A. Rudel, 2019: Environmental justice and drinking water quality: Are there socioeconomic disparities in nitrate levels in U.S. drinking water? *Environmental Health*, **18** (1), 3. https://doi.org/10.1186/s12940-018-0442-6

81. Dobbin, K.B. and M. Lubell, 2021: Collaborative governance and environmental justice: Disadvantaged community representation in California sustainable groundwater management. *Policy Studies Journal*, **49** (2), 562–590. https://doi.org/10.1111/psj.12375

82. Conrad, E., T. Moran, M.E. DuPraw, D. Ceppos, J. Martinez, and W. Blomquist, 2018: Diverse stakeholders create collaborative, multilevel basin governance for groundwater sustainability. *California Agriculture*, **72** (1), 44–53. https://doi.org/10.3733/ca.2018a0002

83. Gilson, G.G. and D.E. Garrick, 2021: Can philanthropy enable collective action to conserve rivers? Insights from a decade of collaboration in the Colorado River Basin. *Conservation and Society*, **19** (3), 190–194. https://doi.org/10.4103/cs.cs_225_20

84. Garcia, M., E. Koebele, A. Deslatte, K. Ernst, K.F. Manago, and G. Treuer, 2019: Towards urban water sustainability: Analyzing management transitions in Miami, Las Vegas, and Los Angeles. *Global Environmental Change*, **58**, 101967. https://doi.org/10.1016/j.gloenvcha.2019.101967

85. Perry, M.D. and S.J. Praskievicz, 2017: A new era of big infrastructure? (Re)developing water storage in the U.S. West in the context of climate change and environmental regulation. *Water Alternatives*, **10** (2), 437–454. https://www.water-alternatives.org/index.php/alldoc/articles/vol10/v10issue2/363-a10-2-13/file

86. Quay, R., F. Sternlieb, E. Rauh, R. Andrade, A. Bartholomew, D. White, J. Holway, Z. Sugg, and E. Rugland, 2022: Evaluating the effectiveness of land and water integrative practices for achieving water sustainability within the Colorado River Basin: Perceptions and indicators. *Water International*, **47** (2), 257–277. https://doi.org/10.1080/02508060.2022.2041281

87. Sterle, K. and L. Singletary, 2017: Adapting to variable water supply in the Truckee-Carson River system, western USA. *Water*, **9** (10), 768. https://doi.org/10.3390/w9100768

88. White, D.D., E.K. Rauh, A. Sullivan, K.L. Larson, A. Wutich, D. Linthicum, V. Horvath, and K.L. Lawless, 2019: Public attitudes toward urban water sustainability transitions: A multi-city survey in the western United States. *Sustainability Science*, **14** (6), 1469–1483. https://doi.org/10.1007/s11625-019-00658-z

89. Obringer, R. and D.D. White, 2023: Leveraging unsupervised learning to develop a typology of residential water users' attitudes towards conservation. *Water Resources Management*, **37** (1), 37–53. https://doi.org/10.1007/s11269-022-03354-3

90. USBR, 2021: Reclamation Announces 2022 Operating Conditions for Lake Powell and Lake Mead. U.S. Bureau of Reclamation. https://www.usbr.gov/newsroom/news-release/3950

91. Black & Veatch, 2020: Binational Study of Water Desalination Opportunities in the Sea of Cortez. TM1: Water Supply Availability and Demand Analysis. Prepared for Minute 323 Desalination Work Group. B&V Project No. 400584. Black & Veatch. https://www.ibwc.gov/wp-content/uploads/2023/04/TMs_All_Portfolio.pdf

92. OCM, 2023: California. National Oceanic and Atmospheric Administration, National Ocean Service, Office for Coastal Management, accessed July 19, 2023. https://coast.noaa.gov/states/california.html

93. OCM, 2015: The National Significance of California's Ocean Economy. National Oceanic and Atmospheric Administration, National Ocean Service, Office for Coastal Management. https://coast.noaa.gov/digitalcoast/training/california-ocean-economy.html

94. CalEPA, 2018: Coastal Ocean Temperature: Ocean Waters Along California's Coast Are Warming. California Environmental Protection Agency, Office of Environmental Health Hazard Assessment, 2 pp. https://oehha.ca.gov/media/epic/downloads/15coastoceantemp_19dec2018.pdf

95. IPCC, 2021: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou, Eds. Cambridge University Press, Cambridge, UK and New York, NY, USA, 2391 pp. https://doi.org/10.1017/9781009157896

96. Pozo Buil, M., M.G. Jacox, J. Fiechter, M.A. Alexander, S.J. Bograd, E.N. Curchitser, C.A. Edwards, R.R. Rykaczewski, and C.A. Stock, 2021: A dynamically downscaled ensemble of future projections for the California Current System. *Frontiers in Marine Science*, **8**, 612874. https://doi.org/10.3389/fmars.2021.612874

97. Di Lorenzo, E. and N. Mantua, 2016: Multi-year persistence of the 2014/15 North Pacific marine heatwave. *Nature Climate Change*, **6**, 1042–1047. https://doi.org/10.1038/nclimate3082

98. Fumo, J.T., M.L. Carter, R.E. Flick, L.L. Rasmussen, D.L. Rudnick, and S.F. Iacobellis, 2020: Contextualizing marine heatwaves in the Southern California Bight under anthropogenic climate change. *Journal of Geophysical Research: Oceans*, **125** (5), e2019JC015674. https://doi.org/10.1029/2019jc015674

99. Oliver, E.C.J., M.G. Donat, M.T. Burrows, P.J. Moore, D.A. Smale, L.V. Alexander, J.A. Benthuysen, M. Feng, A. Sen Gupta, A.J. Hobday, N.J. Holbrook, S.E. Perkins-Kirkpatrick, H.A. Scannell, S.C. Straub, and T. Wernberg, 2018: Longer and more frequent marine heatwaves over the past century. *Nature Communications*, **9** (1), 1324. https://doi.org/10.1038/s41467-018-03732-9

100. Shi, H., M. García-Reyes, M.G. Jacox, R.R. Rykaczewski, B.A. Black, S.J. Bograd, and W.J. Sydeman, 2021: Co-occurrence of California drought and northeast Pacific marine heatwaves under climate change. *Geophysical Research Letters*, **48** (17), e2021GL092765. https://doi.org/10.1029/2021gl092765

101. Nielsen, J.M., L.A. Rogers, R.D. Brodeur, A.R. Thompson, T.D. Auth, A.L. Deary, J.T. Duffy-Anderson, M. Galbraith, J.A. Koslow, and R.I. Perry, 2021: Responses of ichthyoplankton assemblages to the recent marine heatwave and previous climate fluctuations in several Northeast Pacific marine ecosystems. *Global Change Biology*, **27** (3), 506–520. https://doi.org/10.1111/gcb.15415

102. Koenigstein, S., M.G. Jacox, M. Pozo Buil, J. Fiechter, B.A. Muhling, S. Brodie, P.T. Kuriyama, T.D. Auth, E.L. Hazen, S.J. Bograd, and D. Tommasi, 2022: Population projections of Pacific sardine driven by ocean warming and changing food availability in the California Current. *ICES Journal of Marine Science*, **79** (9), 2510–2523. https://doi.org/10.1093/icesjms/fsac191

103. von Biela, V.R., M.L. Arimitsu, J.F. Piatt, B. Heflin, S.K.T.J.L. Schoen, and C.M. Clawson, 2019: Extreme reduction in nutritional value of a key forage fish during the Pacific marine heatwave of 2014–2016. *Marine Ecology Progress Series*, **613**, 171–182. https://doi.org/10.3354/meps12891

104. Jones, T., J.K. Parrish, W.T. Peterson, E.P. Bjorkstedt, N.A. Bond, L.T. Ballance, V. Bowes, J.M. Hipfner, H.K. Burgess, J.E. Dolliver, K. Lindquist, J. Lindsey, H.M. Nevins, R.R. Robertson, J. Roletto, L. Wilson, T. Joyce, and J. Harvey, 2018: Massive mortality of a planktivorous seabird in response to a marine heatwave. *Geophysical Research Letters*, **45** (7), 3193–3202. https://doi.org/10.1002/2017gl076164

105. Piatt, J.F., J.K. Parrish, H.M. Renner, S.K. Schoen, T.T. Jones, M.L. Arimitsu, K.J. Kuletz, B. Bodenstein, M. García-Reyes, R.S. Duerr, R.M. Corcoran, R.S.A. Kaler, G.J. McChesney, R.T. Golightly, H.A. Coletti, R.M. Suryan, H.K. Burgess, J. Lindsey, K. Lindquist, P.M. Warzybok, J. Jahncke, J. Roletto, and W.J. Sydeman, 2020: Extreme mortality and reproductive failure of common murres resulting from the northeast Pacific marine heatwave of 2014–2016. *PLoS ONE*, **15** (1), e0226087. https://doi.org/10.1371/journal.pone.0226087

106. Tolowa Dee-ni' Nation, InterTribal Sinkyone Wilderness Council, Cher-Ae Heights Indian Community of the Trinidad Rancheria, and Wiyot Tribe, 2017: Informing the North Coast MPA Baseline: Traditional Ecological Knowledge of Keystone Marine Species and Ecosystems. University of California, San Diego. https://caseagrant.ucsd.edu/sites/default/files/39-Rocha-Final.pdf

107. Cheung, W.W.L. and T.L. Frölicher, 2020: Marine heatwaves exacerbate climate change impacts for fisheries in the northeast Pacific. *Scientific Reports*, **10** (1), 6678. https://doi.org/10.1038/s41598-020-63650-z

108. Fisher, M.C., S.K. Moore, S.L. Jardine, J.R. Watson, and J.F. Samhouri, 2021: Climate shock effects and mediation in fisheries. *Proceedings of the National Academy of Sciences of the United States of America*, **118** (2), e2014379117. https://doi.org/10.1073/pnas.2014379117

109. Smith, J.A., M. Pozo Buil, B. Muhling, D. Tommasi, S. Brodie, T.H. Frawley, J. Fiechter, S. Koenigstein, A. Himes-Cornell, M.A. Alexander, S.J. Bograd, N. Cordero Quirós, L.B. Crowder, E. Curchitser, S.J. Green, N.A. Hardy, A.C. Haynie, E.L. Hazen, K. Holsman, G. Le Fol, N. Lezama-Ochoa, R.R. Rykaczewski, C.A. Stock, S. Stohs, J. Sweeney, H. Welch, and M.G. Jacox, 2023: Projecting climate change impacts from physics to fisheries: A view from three California Current fisheries. *Progress in Oceanography*, **211**, 102973. https://doi.org/10.1016/j.pocean.2023.102973

110. CalEPA, 2022: Indicators of Climate Change in California: Impacts on Tribes. California Environmental Protection Agency, Office of Environmental Health Hazard Assessment. https://oehha.ca.gov/media/tribalsection2022.pdf

111. Wei, X., K.-Y. Li, T. Kilpatrick, M. Wang, and S.-P. Xie, 2021: Large-scale conditions for the record-setting Southern California marine heatwave of August 2018. *Geophysical Research Letters*, **48** (7), e2020GL091803. https://doi.org/10.1029/2020gl091803

112. Chen, Z., J. Shi, Q. Liu, H. Chen, and C. Li, 2021: A persistent and intense marine heatwave in the Northeast Pacific during 2019–2020. *Geophysical Research Letters*, **48** (13), e2021GL093239. https://doi.org/10.1029/2021gl093239

113. McCabe, R.M., B.M. Hickey, R.M. Kudela, K.A. Lefebvre, N.G. Adams, B.D. Bill, F.M.D. Gulland, R.E. Thomson, W.P. Cochlan, and V.L. Trainer, 2016: An unprecedented coastwide toxic algal bloom linked to anomalous ocean conditions. *Geophysical Research Letters*, **43** (19), 10366–10376. https://doi.org/10.1002/2016gl070023

114. Holland, D.S. and J. Leonard, 2020: Is a delay a disaster? Economic impacts of the delay of the california Dungeness crab fishery due to a harmful algal bloom. *Harmful Algae*, **98**, 101904. https://doi.org/10.1016/j.hal.2020.101904

115. Samhouri, J.F., B.E. Feist, M.C. Fisher, O. Liu, S.M. Woodman, B. Abrahms, K.A. Forney, E.L. Hazen, D. Lawson, J. Redfern, and L.E. Saez, 2021: Marine heatwave challenges solutions to human-wildlife conflict. *Proceedings of the Royal Society B: Biological Sciences*, **288** (1964), 20211607. https://doi.org/10.1098/rspb.2021.1607

116. Santora, J.A., N.J. Mantua, I.D. Schroeder, J.C. Field, E.L. Hazen, S.J. Bograd, W.J. Sydeman, B.K. Wells, J. Calambokidis, L. Saez, D. Lawson, and K.A. Forney, 2020: Habitat compression and ecosystem shifts as potential links between marine heatwave and record whale entanglements. *Nature Communications*, **11** (1), 536. https://doi.org/10.1038/s41467-019-14215-w

117. Rogers-Bennett, L. and C.A. Catton, 2019: Marine heat wave and multiple stressors tip bull kelp forest to sea urchin barrens. *Scientific Reports*, **9** (1), 15050. https://doi.org/10.1038/s41598-019-51114-y

118. Rogers-Bennett, L., R. Klamt, and C.A. Catton, 2021: Survivors of climate driven abalone mass mortality exhibit declines in health and reproduction following kelp forest collapse. *Frontiers in Marine Science*, **8**, 725134. https://doi.org/10.3389/fmars.2021.725134

119. Jardine, S.L., M.C. Fisher, S.K. Moore, and J.F. Samhouri, 2020: Inequality in the economic impacts from climate shocks in fisheries: The case of harmful algal blooms. *Ecological Economics*, **176**, 106691. https://doi.org/10.1016/j.ecolecon.2020.106691

120. Freedman, R.M., J.A. Brown, C. Caldow, and J.E. Caselle, 2020: Marine protected areas do not prevent marine heatwave-induced fish community structure changes in a temperate transition zone. *Scientific Reports*, **10** (1), 21081. https://doi.org/10.1038/s41598-020-77885-3

121. Kawana, S.K., C.A. Catton, J.K.K. Hofmeister, C.I. Juhasz, I.K. Taniguchi, D.M. Stein, and L. Rogers-Bennett, 2019: Warm water shifts abalone recruitment and sea urchin diversity in Southern California: Implications for climate-ready abalone restoration planning. *Journal of Shellfish Research*, **38** (2), 475–484. https://doi.org/10.2983/035.038.0231

122. Munsch, S.H., C.M. Greene, N.J. Mantua, and W.H. Satterthwaite, 2022: One hundred-seventy years of stressors erode salmon fishery climate resilience in California's warming landscape. *Global Change Biology*, **28** (7), 2183–2201. https://doi.org/10.1111/gcb.16029

123. Holsman, K.K., A.C. Haynie, A.B. Hollowed, J.C.P. Reum, K. Aydin, A.J. Hermann, W. Cheng, A. Faig, J.N. Ianelli, K.A. Kearney, and A.E. Punt, 2020: Ecosystem-based fisheries management forestalls climate-driven collapse. *Nature Communications*, **11** (1), 4579. https://doi.org/10.1038/s41467-020-18300-3

124. Ekstrom, J.A., S.K. Moore, and T. Klinger, 2020: Examining harmful algal blooms through a disaster risk management lens: A case study of the 2015 U.S. West Coast domoic acid event. *Harmful Algae*, **94**, 101740. https://doi.org/10.1016/j.hal.2020.101740

125. Hartog, J.R., C.M. Spillman, G. Smith, and A.J. Hobday, 2023: Forecasts of marine heatwaves for marine industries: Reducing risk, building resilience and enhancing management responses. *Deep Sea Research Part II: Topical Studies in Oceanography*, **209**, 105276. https://doi.org/10.1016/j.dsr2.2023.105276

126. Fiechter, J., M. Pozo Buil, M.G. Jacox, M.A. Alexander, and K.A. Rose, 2021: Projected shifts in 21st century sardine distribution and catch in the California Current. *Frontiers in Marine Science*, **8**, 685241. https://doi.org/10.3389/fmars.2021.685241

127. Clements, J.C. and T. Chopin, 2017: Ocean acidification and marine aquaculture in North America: Potential impacts and mitigation strategies. *Reviews in Aquaculture*, **9** (4), 326–341. https://doi.org/10.1111/raq.12140

128. Klinger, T., E.A. Chornesky, E.A. Whiteman, F. Chan, J.L. Largier, and W.W. Wakefield, 2017: Using integrated, ecosystem-level management to address intensifying ocean acidification and hypoxia in the California Current large marine ecosystem. *Elementa: Science of the Anthropocene*, **5**, 16. https://doi.org/10.1525/elementa.198

129. Beheshti, K.M., S.L. Williams, K.E. Boyer, C. Endris, A. Clemons, T. Grimes, K. Wasson, and B.B. Hughes, 2022: Rapid enhancement of multiple ecosystem services following the restoration of a coastal foundation species. *Ecological Applications*, **32** (1), e02466. https://doi.org/10.1002/eap.2466

130. Hirsh, H.K., K.J. Nickols, Y. Takeshita, S.B. Traiger, D.A. Mucciarone, S. Monismith, and R.B. Dunbar, 2020: Drivers of biogeochemical variability in a central California kelp forest: Implications for local amelioration of ocean acidification. *Journal of Geophysical Research: Oceans*, **125** (11), e2020JC016320. https://doi.org/10.1029/2020jc016320

131. Chavez, F.P., C. Costello, D. Aseltine-Neilson, H. Doremus, J.C. Field, S.D. Gaines, M. Hall-Arber, N.J. Mantua, B. McCovey, C. Pomeroy, L. Sievanen, W. Sydeman, and S.A. Wheeler, 2017: Readying California Fisheries for Climate Change. California Ocean Science Trust, Oakland, CA. https://www.oceansciencetrust.org/wp-content/uploads/2016/06/Climate-and-Fisheries_GuidanceDoc.pdf

132. Alleway, H.K., C.L. Gillies, M.J. Bishop, R.R. Gentry, S.J. Theuerkauf, and R. Jones, 2019: The ecosystem services of marine aquaculture: Valuing benefits to people and nature. *BioScience*, **69** (1), 59–68. https://doi.org/10.1093/biosci/biy137

133. Froehlich, H.E., J.C. Afflerbach, M. Frazier, and B.S. Halpern, 2019: Blue growth potential to mitigate climate change through seaweed offsetting. *Current Biology*, **29** (18), 3087–3093. https://doi.org/10.1016/j.cub.2019.07.041

134. Froehlich, H.E., R.R. Gentry, and B.S. Halpern, 2017: Conservation aquaculture: Shifting the narrative and paradigm of aquaculture's role in resource management. *Biological Conservation*, **215**, 162–168. https://doi.org/10.1016/j.biocon.2017.09.012

135. Theuerkauf, S.J., B.J. Puckett, and D.B. Eggleston, 2021: Metapopulation dynamics of oysters: Sources, sinks, and implications for conservation and restoration. *Ecosphere*, **12** (7), e03573. https://doi.org/10.1002/ecs2.3573

136. Kübler, J.E., S.R. Dudgeon, and D. Bush, 2021: Climate change challenges and opportunities for seaweed aquaculture in California, the United States. *Journal of the World Aquaculture Society*, **52** (5), 1069–1080. https://doi.org/10.1111/jwas.12794

137. Titus, J.G., 2023: Population in floodplains or close to sea level increased in US but declined in some counties—Especially among black residents. *Environmental Research Letters*, **18** (3), 034001. https://doi.org/10.1088/1748-9326/acadf5

138. Befus, K.M., P.L. Barnard, D.J. Hoover, J.A. Finzi Hart, and C.I. Voss, 2020: Increasing threat of coastal groundwater hazards from sea-level rise in California. *Nature Climate Change*, **10** (10), 946–952. https://doi.org/10.1038/s41558-020-0874-1

139. Bruzgul, J., R. Kay, A. Petrow, T. Hendrickson, B. Rodehorst, D. Revell, M. Bruguera, D. Moreno, and K. Collison, 2018: Rising Seas and Electricity Infrastructure: Potential Impacts and Adaptation Actions for San Diego Gas & Electric. California's Fourth Climate Change Assessment. Publication Number: CCCA4-CEC-2018-004. California Energy Commission. https://www.energy.ca.gov/sites/default/files/2019-11/energy_ccca4-cec-2018-004_ada.pdf

140. Buchanan, M.K., S. Kulp, L. Cushing, R. Morello-Frosch, T. Nedwick, and B. Strauss, 2020: Sea level rise and coastal flooding threaten affordable housing. *Environmental Research Letters*, **15** (12), 124020. https://doi.org/10.1088/1748-9326/abb266

141. Hoover, D.J., K.O. Odigie, P.W. Swarzenski, and P. Barnard, 2017: Sea-level rise and coastal groundwater inundation and shoaling at select sites in California, USA. *Journal of Hydrology: Regional Studies*, **11**, 234–249. https://doi.org/10.1016/j.ejrh.2015.12.055

142. Nicholls, R.J., D. Lincke, J. Hinkel, S. Brown, A.T. Vafeidis, B. Meyssignac, S.E. Hanson, J.-L. Merkens, and J. Fang, 2021: A global analysis of subsidence, relative sea-level change and coastal flood exposure. *Nature Climate Change*, **11** (4), 338–342. https://doi.org/10.1038/s41558-021-00993-z

143. Radke, J.D., G.S. Biging, K. Roberts, M. Schmidt-Poolman, H. Foster, E. Roe, Y. Ju, S. Lindbergh, T. Beach, L. Maier, Y. He, M. Ashenfarb, P. Norton, M. Wray, A. Alruheili, S. Yi, R. Rau, J. Collins, D. Radke, M. Coufal, S. Marx, A. Gohar, D. Moanga, V. Ulyashin, and A. Dalal, 2018: Assessing Extreme Weather-Related Vulnerability and Identifying Resilience Options for California's Interdependent Transportation Fuel Sector. California's Fourth Climate Change Assessment. Publication Number: CCCA4-CEC-2018-012. California Energy Commission. https://www.energy.ca.gov/sites/default/files/2019-11/energy_ccca4-cec-2018-012_ada.pdf

144. Caltrans, 2022: Sea Level Rise and the Transportation System in the Coastal Zone. California Department of Transportation. https://dot.ca.gov/programs/environmental-analysis/coastal-program/coastal-act-policy-resource-information/coastal-hazards/sea-level-rise

145. Martinich, J., J. Neumann, L. Ludwig, and L. Jantarasami, 2013: Risks of sea level rise to disadvantaged communities in the United States. *Mitigation and Adaptation Strategies for Global Change*, **18** (2), 169–185. https://doi.org/10.1007/s11027-011-9356-0

146. Kopp, R.E., R.M. Horton, C.M. Little, J.X. Mitrovica, M. Oppenheimer, D.J. Rasmussen, B.H. Strauss, and C. Tebaldi, 2014: Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites. *Earth's Future*, **2** (8), 383–406. https://doi.org/10.1002/2014ef000239

147. Tebaldi, C., B.H. Strauss, and C.E. Zervas, 2012: Modelling sea level rise impacts on storm surges along US coasts. *Environmental Research Letters*, **7** (1), 014032. https://doi.org/10.1088/1748-9326/7/1/014032

148. Morello-Frosch, R., 2020: Toxic Tides: Sea Level Rise, Hazardous Sites, and Environmental Justice in California. University of California, Berkeley. https://sites.google.com/berkeley.edu/toxictides/home

149. OEHHA, 2021: CalEnviroScreen 4.0. California Office of Environmental Health Hazard Assessment. https://oehha.ca.gov/calenviroscreen/report/calenviroscreen-40

150. Keenan, J.M., T. Hill, and A. Gumber, 2018: Climate gentrification: From theory to empiricism in Miami-Dade County, Florida. *Environmental Research Letters*, **13** (5), 054001. https://doi.org/10.1088/1748-9326/aabb32

151. Blackwell, E., M. Shirzaei, C. Ojha, and S. Werth, 2020: Tracking California's sinking coast from space: Implications for relative sea-level rise. *Science Advances*, **6** (31), 4551. https://doi.org/10.1126/sciadv.aba4551

152. Fu, X., 2020: Measuring local sea-level rise adaptation and adaptive capacity: A national survey in the United States. *Cities*, **102**, 102717. https://doi.org/10.1016/j.cities.2020.102717

153. Moser, S.C., J.A. Finzi Hart, A.G. Newton Mann, N. Sadrpour, and P.M. Grifman, 2018: Growing Effort, Growing Challenge: Findings from the 2016 CA Coastal Adaptation Needs Assessment Survey. California's Fourth Climate Change Assessment. CCCA4-EXT-2018-009. California Natural Resources Agency. https://www.energy.ca.gov/sites/default/files/2019-12/Oceans_CCCA4-EXT-2018-009_ada.pdf

154. An Act to Amend Section 65302 of the Government Code, Relating to Land Use. Senate Bill No. 379, Chapter 608, State of California, October 8, 2015. https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201520160SB379

155. CAL OES, 2020: California Adaptation Planning Guide. California Governor's Office of Emergency Services, Mather, CA. https://www.caloes.ca.gov/ca-adaptation-planning-guide-final-june-2020-accessible/

156. State of California, 2015: Executive Order B-30-15: Governor Brown Establishes Most Ambitious Greenhouse Gas Reduction Target in North America. State of California, Office of the Governor, Sacramento, CA. https://www.ca.gov/archive/gov39/2015/04/29/news18938/index.html

157. State of California, 2019: Executive Order N-19-19: To Require the Redoubling of the State's "Efforts to Reduce Greenhouse Gas Emissions and Mitigate the Impacts of Climate Change While Building a Sustainable, Inclusive Economy". State of California, Office of the Governor. https://www.adaptationclearinghouse.org/resources/state-of-california-executive-order-n-19-19.html

158. California Coastal Commission, 2021: Critical Infrastructure at Risk: Sea Level Rise Planning Guidance for California's Coastal Zone. California Coastal Commission, San Francisco, CA. https://www.coastal.ca.gov/climate/slr/vulnerability-adaptation/infrastructure/

159. California Ocean Protection Council, 2018: State of California Sea-Level Rise Guidance 2018 Update. State of California, 84 pp. https://www.adaptationclearinghouse.org/resources/california-sea-level-rise-guidance-2018-update.html

160. Governor's Office of Planning and Research, 2022: The ResilientCA Adaptation Planning Map (RAP-Map). State of California, Governor's Office of Planning and Research. https://resilientca.org/rap-map/

161. Moser, S.C., J.A. Ekstrom, J. Kim, and S. Heitsch, 2018: Adaptation Finance Challenges: Characteristic Patterns Facing California Local Governments and Ways to Overcome Them. California's Fourth Climate Change Assessment. Publication Number: CCCA4-CNRA2018-007. California Natural Resources Agency. https://www.energy.ca.gov/sites/default/files/2019-12/governance_ccca4-cnra-2018-007_ada.pdf

162. Matthews, S.N., L.R. Iverson, M.P. Peters, and A.M. Prasad, 2018: Assessing Potential Climate Change Pressures Across the Conterminous United States: Mapping Plant Hardiness Zones, Heat Zones, Growing Degree Days, and Cumulative Drought Severity Throughout This Century. RMAP-NRS-9. U.S. Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, PA, 31 pp. https://doi.org/10.2737/nrs-rmap-9

163. Marklein, A., E. Elias, P. Nico, and K. Steenwerth, 2020: Projected temperature increases may require shifts in the growing season of cool-season crops and the growing locations of warm-season crops. *Science of The Total Environment*, **746**, 140918. https://doi.org/10.1016/j.scitotenv.2020.140918

164. Jin, Y., B. Chen, B.D. Lampinen, and P.H. Brown, 2020: Advancing agricultural production with machine learning analytics: Yield determinants for California's almond orchards. *Frontiers in Plant Science*, **11**, 290. https://doi.org/10.3389/fpls.2020.00290

165. Parker, L.E., N. Zhang, J.T. Abatzoglou, S.M. Ostoja, and T.B. Pathak, 2022: Observed changes in agroclimate metrics relevant for specialty crop production in California. *Agronomy*, **12** (1), 205. https://doi.org/10.3390/agronomy12010205

166. Kral-O'Brien, K.C., P.L. O'Brien, and J.P. Harmon, 2019: Need for false spring research in the northern Great Plains, USA. *Agricultural & Environmental Letters*, **4** (1), 190025. https://doi.org/10.2134/ael2019.07.0025

167. Guirguis, K., A. Gershunov, D.R. Cayan, and D.W. Pierce, 2018: Heat wave probability in the changing climate of the Southwest US. *Climate Dynamics*, **50** (9–10), 3853–3864. https://doi.org/10.1007/s00382-017-3850-3

168. Ayankojo, I.T., K.R. Thorp, K. Morgan, K. Kothari, and S. Ale, 2020: Assessing the impacts of future climate on cotton production in the Arizona low desert. *Transactions of the ASABE*, **63** (4), 1087–1098. https://doi.org/10.13031/trans.13731

169. Pathak, T.B., M.L. Maskey, J.A. Dahlberg, F. Kearns, K.M. Bali, and D. Zaccaria, 2018: Climate change trends and impacts on California agriculture: A detailed review. *Agronomy*, **8** (3), 25. https://doi.org/10.3390/agronomy8030025

170. Conrad, L.M., A.G. Fernald, S.J. Guldan, and C.G. Ochoa, 2022: A water balancing act: Water balances highlight the benefits of community-based adaptive management in northern New Mexico, USA. *Hydrology*, **9** (4), 64. https://doi.org/10.3390/hydrology9040064

171. Duniway, M.C., A.A. Pfennigwerth, S.E. Fick, T.W. Nauman, J. Belnap, and N.N. Barger, 2019: Wind erosion and dust from US drylands: A review of causes, consequences, and solutions in a changing world. *Ecosphere*, **10** (3), e02650. https://doi.org/10.1002/ecs2.2650

172. Finger-Higgens, R., M.C. Duniway, S. Fick, E.L. Geiger, D.L. Hoover, A.A. Pfennigwerth, M.W. Van Scoyoc, and J. Belnap, 2022: Decline in biological soil crust N-fixing lichens linked to increasing summertime temperatures. *Proceedings of the National Academy of Sciences of the United States of America*, **119** (16), e2120975119. https://doi.org/10.1073/pnas.2120975119

173. Fassnacht, S.R., C.R. Duncan, A.K.D. Pfohl, R.W. Webb, J.E. Derry, W.E. Sanford, D.C. Reimanis, and L.G. Doskocil, 2022: Drivers of dust-enhanced snowpack melt-out and streamflow timing. *Hydrology*, **9** (3), 47. https://doi.org/10.3390/hydrology9030047

174. ERS, 2020: Ag and Food Statistics: Charting the Essentials. U.S. Department of Agriculture, Economic Research Service. https://www.ers.usda.gov/data-products/ag-and-food-statistics-charting-the-essentials/

175. CDFA, 2022: California Agricultural Production Statistics. California Department of Food and Agriculture. https://www.cdfa.ca.gov/statistics/

176. NASS, 2022: Data and Statistics, October 2022. U.S. Department of Agriculture, National Agricultural Statistics Service. https://www.nass.usda.gov/data_and_statistics/index.php

177. Parajuli, R., G. Thoma, and M.D. Matlock, 2019: Environmental sustainability of fruit and vegetable production supply chains in the face of climate change: A review. *Science of The Total Environment*, **650**, 2863–2879. https://doi.org/10.1016/j.scitotenv.2018.10.019

178. Davis, K.F., S. Downs, and J.A. Gephart, 2021: Towards food supply chain resilience to environmental shocks. *Nature Food*, **2** (1), 54–65. https://doi.org/10.1038/s43016-020-00196-3

179. Medellín-Azuara, J., A. Escriva-Bou, J.A. Abatzoglou, J.H. Viers, S.A. Cole, J.M. Rodríguez-Flores, and D.A. Sumner, 2022: Economic Impacts of the 2021 Drought on California Agriculture: Preliminary Report. University of California, Merced. https://wsm.ucmerced.edu/wp-content/uploads/2022/02/2021-Drought-Impact-Assessment_20210224.pdf

180. Monteverde, C. and F. De Sales, 2020: Impacts of global warming on southern California's winegrape climate suitability. *Advances in Climate Change Research*, **11** (3), 279–293. https://doi.org/10.1016/j.accre.2020.08.002

181. Parker, L.E., A.J. McElrone, S.M. Ostoja, and E.J. Forrestel, 2020: Extreme heat effects on perennial crops and strategies for sustaining future production. *Plant Science*, **295**, 110397. https://doi.org/10.1016/j.plantsci.2019.110397

182. Hanak, E., A. Escriva-Bou, B. Gray, S. Green, T. Harter, J. Jezdimirovic, J. Lund, J. Medellín-Azuara, P. Moyle, and N. Seavy, 2019: Water and the Future of the San Joaquin Valley. Public Policy Institute of California, 100 pp. https://www.ppic.org/publication/water-and-the-future-of-the-san-joaquin-valley/

183. Morris, J.L., S. Cottrell, C.J. Fettig, R.J. DeRose, K.M. Mattor, V.A. Carter, J. Clear, J. Clement, W.D. Hansen, J.A. Hicke, P.E. Higuera, A.W. Seddon, H. Seppä, R.L. Sherriff, J.D. Stednick, and S.J. Seybold, 2018: Bark beetles as agents of change in social–ecological systems. *Frontiers in Ecology and the Environment*, **16** (S1), S34–S43. https://doi.org/10.1002/fee.1754

184. Standiford, R., S.L. Evans, and J. Henderson, 2020: Economic Contribution of California's Forestry and Forest-Products Sectors. Publication Number: 8670. University of California, Agriculture and Natural Resources, 17 pp. https://anrcatalog.ucanr.edu/details.aspx?itemno=8670

185. Ortiz-Bobea, A., E. Knippenberg, and R.G. Chambers, 2018: Growing climatic sensitivity of U.S. agriculture linked to technological change and regional specialization. *Science Advances*, **4** (12), 4343. https://doi.org/10.1126/sciadv.aat4343

186. Bae, J. and S. Dall'erba, 2018: Crop production, export of virtual water and water-saving strategies in Arizona. *Ecological Economics*, **146**, 148–156. https://doi.org/10.1016/j.ecolecon.2017.10.018

187. York, A.M., H. Eakin, J.C. Bausch, S. Smith-Heisters, J.M. Anderies, R. Aggarwal, B. Leonard, and K. Wright, 2020: Agricultural water governance in the desert: Shifting risks in central Arizona. *Water Alternatives*, **13** (2), 418–445. https://www.water-alternatives.org/index.php/alldoc/articles/vol13/v13issue2/582-a13-2-11/file

188. Abbott, B.W., B.K. Baxter, K. Busche, L.d. Freitas, R. Frei, T. Gomez, M.A. Karren, R.L. Buck, J. Price, S. Frutos, R.B. Sowby, J. Brahney, B.G. Hopkins, M.F. Bekker, J.S. Bekker, R. Rader, B. Brown, M. Proteau, G.T. Carling, L. Conner, P.A. Cox, E. McQuhae, C. Oscarson, D.T. Nelson, R.J. Davis, D. Horns, H. Dove, T. Bishop, A. Johnson, K. Nelson, J. Bennion, and P. Belmont, 2023: Emergency Measures Needed to Rescue Great Salt Lake from Ongoing Collapse. Brigham Young University, College of Life Sciences, Plant and Wildlife Sciences, 34 pp. https://pws.byu.edu/great-salt-lake

189. Reyes, J.J. and E. Elias, 2019: Spatio-temporal variation of crop loss in the United States from 2001 to 2016. *Environmental Research Letters*, **14** (7), 074017. https://doi.org/10.1088/1748-9326/ab1ac9

190. Johnson, K.M. and D.T. Lichter, 2019: Rural depopulation: Growth and decline processes over the past century. *Rural Sociology*, **84** (1), 3–27. https://doi.org/10.1111/ruso.12266

191. Lichter, D.T., D.L. Brown, and D. Parisi, 2021: The rural–urban interface: Rural and small town growth at the metropolitan fringe. *Population, Space and Place*, **27** (3), e2415. https://doi.org/10.1002/psp.2415

192. Ahmed, S. and D. Jackson-Smith, 2019: Impacts of spatial patterns of rural and exurban residential development on agricultural trends in the Intermountain West. *SAGE Open*, **9** (3). https://doi.org/10.1177/2158244019871037

193. Park, S. and S. Deller, 2021: Effect of farm structure on rural community well-being. *Journal of Rural Studies*, **87**, 300–313. https://doi.org/10.1016/j.jrurstud.2021.09.014

194. Stahle, D.W., 2020: Anthropogenic megadrought. *Science*, **368** (6488), 238–239. https://doi.org/10.1126/science.abb6902

195. Havstad, K.M., J.R. Brown, R. Estell, E. Elias, A. Rango, and C. Steele, 2018: Vulnerabilities of southwestern U.S. rangeland-based animal agriculture to climate change. *Climatic Change*, **148** (3), 371–386. https://doi.org/10.1007/s10584-016-1834-7

196. Holechek, J.L., H.M.E. Geli, A.F. Cibils, and M.N. Sawalhah, 2020: Climate change, rangelands, and sustainability of ranching in the western United States. *Sustainability*, **12** (12), 4942. https://doi.org/10.3390/su12124942

197. Brice, E.M., B.A. Miller, H. Zhang, K. Goldstein, S.N. Zimmer, G.J. Grosklos, P. Belmont, C.G. Flint, J.E. Givens, P.B. Adler, M.W. Brunson, and J.W. Smith, 2020: Impacts of climate change on multiple use management of Bureau of Land Management land in the Intermountain West, USA. *Ecosphere*, **11** (11), e03286. https://doi.org/10.1002/ecs2.3286

198. Godde, C.M., D. Mason-D'Croz, D.E. Mayberry, P.K. Thornton, and M. Herrero, 2021: Impacts of climate change on the livestock food supply chain; a review of the evidence. *Global Food Security*, **28**, 100488. https://doi.org/10.1016/j.gfs.2020.100488

199. Dinan, M., P.B. Adler, J. Bradford, M. Brunson, E. Elias, A. Felton, C. Greene, J. James, K. Suding, and E. Thacker, 2021: Making research relevant: Sharing climate change research with rangeland advisors to transform results into drought resilience. *Rangelands*, **43** (5), 185–193. https://doi.org/10.1016/j.rala.2021.08.004

200. Flörke, M., C. Schneider, and R.I. McDonald, 2018: Water competition between cities and agriculture driven by climate change and urban growth. *Nature Sustainability*, **1** (1), 51–58. https://doi.org/10.1038/s41893-017-0006-8

201. Bray, L.A., 2022: Water justice across the rural-urban interface: The making of hydrosocial territories in New Mexico's Rio Grande Valley. *Society & Natural Resources*, **35** (3), 320–337. https://doi.org/10.1080/08941920.2022.2032893

202. Dilling, L., J. Berggren, J. Henderson, and D. Kenney, 2019: Savior of rural landscapes or Solomon's choice? Colorado's experiment with alternative transfer methods for water (ATMs). *Water Security*, **6**, 100027. https://doi.org/10.1016/j.wasec.2019.100027

203. Fulton, J., M. Norton, and F. Shilling, 2019: Water-indexed benefits and impacts of California almonds. *Ecological Indicators*, **96**, 711–717. https://doi.org/10.1016/j.ecolind.2017.12.063

204. Reisman, E., 2019: The great almond debate: A subtle double movement in California water. *Geoforum*, **104**, 137–146. https://doi.org/10.1016/j.geoforum.2019.04.021

205. Morgan, B., K. Spangler, J. Stuivenvolt Allen, C.N. Morrisett, M.W. Brunson, S.-Y.S. Wang, and N. Huntly, 2021: Water availability for cannabis in Northern California: Intersections of climate, policy, and public discourse. *Water*, **13** (1), 5. https://doi.org/10.3390/w13010005

206. Carney, M.A. and K.C. Krause, 2020: Immigration/migration and healthy publics: The threat of food insecurity. *Palgrave Communications*, **6** (1), 93. https://doi.org/10.1057/s41599-020-0461-0

207. Glazebrook, T., S. Noll, and E. Opoku, 2020: Gender matters: Climate change, gender bias, and women's farming in the global South and North. *Agriculture*, **10** (7), 267. https://doi.org/10.3390/agriculture10070267

208. Greene, C., 2018: Broadening understandings of drought—The climate vulnerability of farmworkers and rural communities in California (USA). *Environmental Science & Policy*, **89**, 283–291. https://doi.org/10.1016/j.envsci.2018.08.002

209. Howard, M., S. Ahmed, P. Lachapelle, and M.B. Schure, 2020: Farmer and rancher perceptions of climate change and their relationships with mental health. *Journal of Rural Mental Health*, **44** (2), 87–95. https://doi.org/10.1037/rmh0000131

210. Munden-Dixon, K., K. Tate, B. Cutts, and L. Roche, 2019: An uncertain future: Climate resilience of first-generation ranchers. *The Rangeland Journal*, **41**, 189–196. https://doi.org/10.1071/rj18023

211. Siegner, A., J. Sowerwine, and C. Acey, 2018: Does urban agriculture improve food security? Examining the nexus of food access and distribution of urban produced foods in the United States: A systematic review. *Sustainability*, **10** (9), 2988. https://doi.org/10.3390/su10092988

212. Adger, W.N., J. Barnett, K. Brown, N. Marshall, and K. O'Brien, 2013: Cultural dimensions of climate change impacts and adaptation. *Nature Climate Change*, **3** (2), 112–117. https://doi.org/10.1038/nclimate1666

213. Hepler, M. and E.A. Kronk Warner, 2019: Learning from tribal innovations: Lessons in climate change adaptation. *Environmental Law Reporter*, **49** (11130). https://doi.org/10.2139/ssrn.3444403

214. Nabhan, G.P., E.C. Riordan, L. Monti, A.M. Rea, B.T. Wilder, E. Ezcurra, J.B. Mabry, J. Aronson, G.A. Barron-Gafford, J.M. García, A. Búrquez, T.E. Crews, P. Mirocha, and W.C. Hodgson, 2020: An Aridamerican model for agriculture in a hotter, water scarce world. *Plants, People, Planet*, **2** (6), 627–639. https://doi.org/10.1002/ppp3.10129

215. Sowerwine, J., D. Sarna-Wojcicki, M. Mucioki, L. Hillman, F. Lake, and E. Friedman, 2019: Enhancing food sovereignty: A five-year collaborative Tribal-University research and extension project in California and Oregon. *Journal of Agriculture, Food Systems, and Community Development*, **9** (B), 167–190. https://doi.org/10.5304/jafscd.2019.09b.013

216. Gosnell, H., S. Charnley, and P. Stanley, 2020: Climate change mitigation as a co-benefit of regenerative ranching: Insights from Australia and the United States. *Interface Focus*, **10** (5), 20200027. https://doi.org/10.1098/rsfs.2020.0027

217. Shrum, T.R., W.R. Travis, T.M. Williams, and E. Lih, 2018: Managing climate risks on the ranch with limited drought information. *Climate Risk Management*, **20**, 11–26. https://doi.org/10.1016/j.crm.2018.01.002

218. Mitchell, J.P., D.C. Reicosky, E.A. Kueneman, J. Fisher, and D. Beck, 2019: Conservation agriculture systems. *CABI Reviews*, **2019**, 1–25. https://doi.org/10.1079/pavsnnr201914001

219. Mpanga, I.K., G. Neumann, U.K. Schuch, and J. Schalau, 2020: Sustainable agriculture practices as a driver for increased harvested cropland among large-scale growers in Arizona: A paradox for small-scale growers. *Advanced Sustainable Systems*, **4** (4), 1900143. https://doi.org/10.1002/adsu.201900143

220. Kelly, C., S.J. Fonte, A. Shrestha, K.M. Daane, and J.P. Mitchell, 2021: Winter cover crops and no-till promote soil macrofauna communities in irrigated, Mediterranean cropland in California, USA. *Applied Soil Ecology*, **166**, 104068. https://doi.org/10.1016/j.apsoil.2021.104068

221. Paye, W.S., R. Ghimire, P. Acharya, A. Nilahyane, A.O. Mesbah, and M.A. Marsalis, 2022: Cover crop water use and corn silage production in semi-arid irrigated conditions. *Agricultural Water Management*, **260**, 107275. https://doi.org/10.1016/j.agwat.2021.107275

222. Thapa, V.R., R. Ghimire, D. VanLeeuwen, V. Acosta-Martínez, and M. Shukla, 2022: Response of soil organic matter to cover cropping in water-limited environments. *Geoderma*, **406**, 115497. https://doi.org/10.1016/j.geoderma.2021.115497

223. Babin, N., C. Klier, and A. Singh, 2022: Understanding and promoting adoption of irrigation efficiency practices in Paso Robles, California vineyards: The importance of farm typology and grower sustainability networks. *Current Research in Environmental Sustainability*, **4**, 100143. https://doi.org/10.1016/j.crsust.2022.100143

224. Douglass-Gallagher, E. and D. Stuart, 2019: Crop growers' adaptive capacity to climate change: A situated study of agriculture in Arizona's Verde Valley. *Environmental Management*, **63** (1), 94–109. https://doi.org/10.1007/s00267-018-1114-6

225. Johnson, M.K., A.M. Lien, N.R. Sherman, and L. López-Hoffman, 2018: Barriers to PES programs in Indigenous communities: A lesson in land tenure insecurity from the Hopi Indian reservation. *Ecosystem Services*, **32**, 62–69. https://doi.org/10.1016/j.ecoser.2018.05.009

226. Johnson, M.K., M.J. Rowe, A. Lien, and L. López-Hoffman, 2021: Enhancing integration of indigenous agricultural knowledge into USDA Natural Resources Conservation Service cost-share initiatives. *Journal of Soil and Water Conservation*, **76** (6), 487. https://doi.org/10.2489/jswc.2021.00179

227. MCDPH, 2021: Heat Reports. Maricopa County Department of Public Health, accessed August 15, 2022. https://www.maricopa.gov/1858/heat-surveillance

228. Putnam, H., D.M. Hondula, A. Urban, V. Berisha, P. Iñiguez, and M. Roach, 2018: It's not the heat, it's the vulnerability: Attribution of the 2016 spike in heat-associated deaths in Maricopa County, Arizona. *Environmental Research Letters*, **13** (9), 094022. https://doi.org/10.1088/1748-9326/aadb44

229. Schwarz, L., E.M. Castillo, T.C. Chan, J.J. Brennan, E.S. Sbiroli, G. Carrasco-Escobar, A. Nguyen, R.E.S. Clemesha, A. Gershunov, and T. Benmarhnia, 2022: Heat waves and emergency department visits among the homeless, San Diego, 2012–2019. *American Journal of Public Health*, **112** (1), 98–106. https://doi.org/10.2105/ajph.2021.306557

230. López-Carr, D., J. Vanos, A. Sánchez-Vargas, R. Vargas, and F. Castillo, 2022: Extreme heat and COVID-19: A dual burden for farmworkers. *Frontiers in Public Health*, **10**, 884152. https://doi.org/10.3389/fpubh.2022.884152

231. Méndez, M., G. Flores-Haro, and L. Zucker, 2020: The (in)visible victims of disaster: Understanding the vulnerability of undocumented Latino/a and Indigenous immigrants. *Geoforum*, **116**, 50–62. https://doi.org/10.1016/j.geoforum.2020.07.007

232. Mitchell, D.C., J. Castro, T.L. Armitage, A.J. Vega-Arroyo, S.C. Moyce, D.J. Tancredi, D.H. Bennett, J.H. Jones, T. Kjellstrom, and M.B. Schenker, 2017: Recruitment, methods, and descriptive results of a physiologic assessment of Latino farmworkers: The California heat illness prevention study. *Journal of Occupational and Environmental Medicine*, **59** (7). https://doi.org/10.1097/jom.0000000000000988

233. Taylor, E.V., A. Vaidyanathan, W.D. Flanders, M. Murphy, M. Spencer, and R.S. Noe, 2018: Differences in heat-related mortality by citizenship status: United States, 2005–2014. *American Journal of Public Health*, **108** (S2), S131–S136. https://doi.org/10.2105/ajph.2017.304006

234. Guardaro, M., D.M. Hondula, J. Ortiz, and C.L. Redman, 2022: Adaptive capacity to extreme urban heat: The dynamics of differing narratives. *Climate Risk Management*, **35**, 100415. https://doi.org/10.1016/j.crm.2022.100415

235. Jay, O., A. Capon, P. Berry, C. Broderick, R. de Dear, G. Havenith, Y. Honda, R.S. Kovats, W. Ma, A. Malik, N.B. Morris, L. Nybo, S.I. Seneviratne, J. Vanos, and K.L. Ebi, 2021: Reducing the health effects of hot weather and heat extremes: From personal cooling strategies to green cities. *The Lancet*, **398** (10301), 709–724. https://doi.org/10.1016/s0140-6736(21)01209-5

236. CDC, 2022: National Environmental Public Health Tracking Network. Centers for Disease Control and Prevention, accessed August 20, 2022. https://ephtracking.cdc.gov/dataexplorer/

237. Avalos, L.A., H. Chen, D.-K. Li, and R. Basu, 2017: The impact of high apparent temperature on spontaneous preterm delivery: A case-crossover study. *Environmental Health*, **16** (1), 5. https://doi.org/10.1186/s12940-017-0209-5

238. Barreca, A. and J. Schaller, 2020: The impact of high ambient temperatures on delivery timing and gestational lengths. *Nature Climate Change*, **10** (1), 77–82. https://doi.org/10.1038/s41558-019-0632-4

239. Ilango, S.D., M. Weaver, P. Sheridan, L. Schwarz, R.E.S. Clemesha, T. Bruckner, R. Basu, A. Gershunov, and T. Benmarhnia, 2020: Extreme heat episodes and risk of preterm birth in California, 2005–2013. *Environment International*, **137**, 105541. https://doi.org/10.1016/j.envint.2020.105541

240. Lu, C., Y. Zhang, B. Li, Z. Zhao, C. Huang, X. Zhang, H. Qian, J. Wang, W. Liu, Y. Sun, D. Norbäck, and Q. Deng, 2022: Interaction effect of prenatal and postnatal exposure to ambient air pollution and temperature on childhood asthma. *Environment International*, **167**, 107456. https://doi.org/10.1016/j.envint.2022.107456

241. Gershunov, A. and K. Guirguis, 2012: California heat waves in the present and future. *Geophysical Research Letters*, **39** (18). https://doi.org/10.1029/2012gl052979

242. EPA, 2021: Climate Change Indicators: Health and Society. U.S. Environmental Protection Agency. https://www.epa.gov/climate-indicators/health-society

243. Prein, A.F., G.J. Holland, R.M. Rasmussen, M.P. Clark, and M.R. Tye, 2016: Running dry: The U.S. Southwest's drift into a drier climate state. *Geophysical Research Letters*, **43** (3), 1272–1279. https://doi.org/10.1002/2015gl066727

244. Achakulwisut, P., S.C. Anenberg, J.E. Neumann, S.L. Penn, N. Weiss, A. Crimmins, N. Fann, J. Martinich, H. Roman, and L.J. Mickley, 2019: Effects of increasing aridity on ambient dust and public health in the U.S. Southwest under climate change. *GeoHealth*, **3** (5), 127–144. https://doi.org/10.1029/2019gh000187

245. McCotter, O.Z., K. Benedict, D.M. Engelthaler, K. Komatsu, K.D. Lucas, J.C. Mohle-Boetani, H. Oltean, D. Vugia, T.M. Chiller, G.L. Sondermeyer Cooksey, A. Nguyen, C.C. Roe, C. Wheeler, and R. Sunenshine, 2019: Update on the Epidemiology of coccidioidomycosis in the United States. *Medical Mycology*, **57** (Supplement_1), S30–S40. https://doi.org/10.1093/mmy/myy095

246. Gorris, M.E., L.A. Cat, C.S. Zender, K.K. Treseder, and J.T. Randerson, 2018: Coccidioidomycosis dynamics in relation to climate in the southwestern United States. *GeoHealth*, **2** (1), 6–24. https://doi.org/10.1002/2017gh000095

247. Head, J.R., G. Sondermeyer-Cooksey, A.K. Heaney, A.T. Yu, I. Jones, A. Bhattachan, S.K. Campo, R. Wagner, W. Mgbara, S. Phillips, N. Keeney, J. Taylor, E. Eisen, D.P. Lettenmaier, A. Hubbard, G.S. Okin, D.J. Vugia, S. Jain, and J.V. Remais, 2022: Effects of precipitation, heat, and drought on incidence and expansion of coccidioidomycosis in western USA: A longitudinal surveillance study. *The Lancet Planetary Health*, **6** (10), e793–e803. https://doi.org/10.1016/s2542-5196(22)00202-9

248. Gorris, M.E., J.E. Neumann, P.L. Kinney, M. Sheahan, and M.C. Sarofim, 2021: Economic valuation of coccidioidomycosis (Valley fever) projections in the United States in response to climate change. *Weather, Climate, and Society*, **13** (1), 107–123. https://doi.org/10.1175/wcas-d-20-0036.1

249. Graff Zivin, J. and M. Neidell, 2014: Temperature and the allocation of time: Implications for climate change. *Journal of Labor Economics*, **32** (1), 1–26. https://doi.org/10.1086/671766

250. Vanos, J., S. Moyce, B. Lemke, and T. Kjellstrom, 2021: Ch. 10. Extreme heat exposure and occupational health in a changing climate. In: *Extreme Events and Climate Change: A Multidisciplinary Approach*. Castillo, F., M. Wehner, and D.A. Stone, Eds. Wiley, 147–166. https://doi.org/10.1002/9781119413738.ch10

251. Zhang, Y. and D.T. Shindell, 2021: Costs from labor losses due to extreme heat in the USA attributable to climate change. *Climatic Change*, **164** (3), 35. https://doi.org/10.1007/s10584-021-03014-2

252. Castillo, F., A.M. Mora, G.L. Kayser, J. Vanos, C. Hyland, A.R. Yang, and B. Eskenazi, 2021: Environmental health threats to Latino migrant farmworkers. *Annual Review of Public Health*, **42** (1), 257–276. https://doi.org/10.1146/annurev-publhealth-012420-105014

253. Stevens, A.W., 2017: Temperature, Wages, and Agricultural Labor Productivity. University of California, Berkeley. https://www.econ.iastate.edu/files/events/files/stevens_jmp_jan16.pdf

254. Moyce, S., J. Joseph, D. Tancredi, D. Mitchell, and M. Schenker, 2016: Cumulative incidence of acute kidney injury in California's agricultural workers. *Journal of Occupational and Environmental Medicine*, **58** (4). https://doi.org/10.1097/jom.0000000000000668

255. Wesseling, C., J. Glaser, J. Rodríguez-Guzmán, I. Weiss, R. Lucas, S. Peraza, A. Soares da Silva, E. Hansson, R.J. Johnson, C. Hogstedt, D.H. Wegman, and K. Jakobsson, 2020: Chronic kidney disease of non-traditional origin in Mesoamerica: A disease primarily driven by occupational heat stress. *Pan American Journal of Public Health*, **44**, 15. https://doi.org/10.26633/rpsp.2020.15

256. Foster, J., J.W. Smallcombe, S. Hodder, O. Jay, A.D. Flouris, and G. Havenith, 2022: Quantifying the impact of heat on human physical work capacity; Part II: The observed interaction of air velocity with temperature, humidity, sweat rate, and clothing is not captured by most heat stress indices. *International Journal of Biometeorology*, **66** (3), 507–520. https://doi.org/10.1007/s00484-021-02212-y

257. Foster, J., J.W. Smallcombe, S. Hodder, O. Jay, A.D. Flouris, L. Nybo, and G. Havenith, 2021: An advanced empirical model for quantifying the impact of heat and climate change on human physical work capacity. *International Journal of Biometeorology*, **65** (7), 1215–1229. https://doi.org/10.1007/s00484-021-02105-0

258. Foster, J., J.W. Smallcombe, S. Hodder, O. Jay, A.D. Flouris, L. Nybo, and G. Havenith, 2022: Quantifying the impact of heat on human physical work capacity; Part III: The impact of solar radiation varies with air temperature, humidity, and clothing coverage. *International Journal of Biometeorology*, **66** (1), 175–188. https://doi.org/10.1007/s00484-021-02205-x

259. Smallcombe, J.W., J. Foster, S.G. Hodder, O. Jay, A.D. Flouris, and G. Havenith, 2022: Quantifying the impact of heat on human physical work capacity; part IV: Interactions between work duration and heat stress severity. *International Journal of Biometeorology*, **66** (12), 2463–2476. https://doi.org/10.1007/s00484-022-02370-7

260. Colmer, J., I. Hardman, J. Shimshack, and J. Voorheis, 2020: Disparities in $PM_{2.5}$ air pollution in the United States. *Science*, **369** (6503), 575–578. https://doi.org/10.1126/science.aaz9353

261. Liang, Y., D. Sengupta, M.J. Campmier, D.M. Lunderberg, J.S. Apte, and A.H. Goldstein, 2021: Wildfire smoke impacts on indoor air quality assessed using crowdsourced data in California. *Proceedings of the National Academy of Sciences of the United States of America*, **118** (36), e2106478118. https://doi.org/10.1073/pnas.2106478118

262. Navarro, K.M., R. Cisneros, D. Schweizer, P. Chowdhary, E.M. Noth, J.R. Balmes, and S.K. Hammond, 2019: Incident command post exposure to polycyclic aromatic hydrocarbons and particulate matter during a wildfire. *Journal of Occupational and Environmental Hygiene*, **16** (11), 735–744. https://doi.org/10.1080/15459624.2019.1657579

263. Fann, N., B. Alman, R.A. Broome, G.G. Morgan, F.H. Johnston, G. Pouliot, and A.G. Rappold, 2018: The health impacts and economic value of wildland fire episodes in the U.S.: 2008–2012. *Science of The Total Environment*, **610–611**, 802–809. https://doi.org/10.1016/j.scitotenv.2017.08.024

264. Yang, X., Y. Yu, S. Shirowzhan, S. sepasgozar, and H. Li, 2020: Automated PPE-tool pair check system for construction safety using smart IoT. *Journal of Building Engineering*, **32**, 101721. https://doi.org/10.1016/j.jobe.2020.101721

265. Aguilera, R., T. Corringham, A. Gershunov, and T. Benmarhnia, 2021: Wildfire smoke impacts respiratory health more than fine particles from other sources: Observational evidence from Southern California. *Nature Communications*, **12** (1), 1493. https://doi.org/10.1038/s41467-021-21708-0

266. Jaffe, D.A., S.M. O'Neill, N.K. Larkin, A.L. Holder, D.L. Peterson, J.E. Halofsky, and A.G. Rappold, 2020: Wildfire and prescribed burning impacts on air quality in the United States. *Journal of the Air & Waste Management Association*, **70** (6), 583–615. https://doi.org/10.1080/10962247.2020.1749731

267. Grant, E. and J.D. Runkle, 2022: Long-term health effects of wildfire exposure: A scoping review. *The Journal of Climate Change and Health*, **6**, 100110. https://doi.org/10.1016/j.joclim.2021.100110

268. Silveira, S., M. Kornbluh, M.C. Withers, G. Grennan, V. Ramanathan, and J. Mishra, 2021: Chronic mental health sequelae of climate change extremes: A case study of the deadliest Californian wildfire. *International Journal of Environmental Research and Public Health*, **18** (4), 1487. https://doi.org/10.3390/ijerph18041487

269. Proctor, C.R., J. Lee, D. Yu, A.D. Shah, and A.J. Whelton, 2020: Wildfire caused widespread drinking water distribution network contamination. *AWWA Water Science*, **2** (4), e1183. https://doi.org/10.1002/aws2.1183

270. National Academies of Sciences, Engineering, and Medicine, 2020: *Implications of the California Wildfires for Health, Communities, and Preparedness: Proceedings of a Workshop*. The National Academies Press, Washington, DC. https://doi.org/10.17226/25622

271. Dong, L., L.R. Leung, J. Lu, and Y. Gao, 2019: Contributions of extreme and non-extreme precipitation to California precipitation seasonality changes under warming. *Geophysical Research Letters*, **46** (22), 13470–13478. https://doi.org/10.1029/2019gl084225

272. Huang, X. and D.L. Swain, 2022: Climate change is increasing the risk of a California megaflood. *Science Advances*, **8** (32), 0995. https://doi.org/10.1126/sciadv.abq0995

273. Semenza, J.C., J. Rocklöv, and K.L. Ebi, 2022: Climate change and cascading risks from infectious disease. *Infectious Diseases and Therapy*, **11** (4), 1371–1390. https://doi.org/10.1007/s40121-022-00647-3

274. NCEZID, 2023: 2022 Provisional Human Data. Centers for Disease Control and Prevention, National Center for Emerging and Zoonotic Infectious Diseases, accessed April 3, 2023. https://wwwn.cdc.gov/arbonet/maps/adb_diseases_map/index.html

275. CA DWR, 2022: Central Valley Flood Protection Plan Update 2022. State of California, Natural Resources Agency, Department of Water Resources. https://water.ca.gov/-/media/dwr-website/web-pages/programs/flood-management/flood-planning-and-studies/central-valley-flood-protection-plan/files/cvfpp-updates/2022/central_valley_flood_protection_plan_update_2022_adopted.pdf

276. Gorris, M.E., A.W. Bartlow, S.D. Temple, D. Romero-Alvarez, D.P. Shutt, J.M. Fair, K.A. Kaufeld, S.Y. Del Valle, and C.A. Manore, 2021: Updated distribution maps of predominant *Culex* mosquitoes across the Americas. *Parasites & Vectors*, **14** (1), 547. https://doi.org/10.1186/s13071-021-05051-3

277. Méndez, M., 2022: Behind the bougainvillea curtain: Wildfires and inequality. *Issues in Science and Technology*, **38** (2), 84–90. https://www.preventionweb.net/publication/behind-bougainvillea-curtain-wildfires-and-inequality

278. CBP, 2020: Southwest Border Migration FY 2020. U.S. Customs and Border Protection. https://www.cbp.gov/newsroom/stats/sw-border-migration-fy2020

279. WFP, 2017: Food Security and Emigration: Why People Flee and the Impact on Family Members Left Behind in El Salvador, Guatemala, and Honduras. United Nations World Food Programme. https://docs.wfp.org/api/documents/wfp-0000019632/download/

280. Bradatan, C., J.A. Dennis, N. Flores-Yeffal, and S. Swain, 2020: Child health, household environment, temperature and rainfall anomalies in Honduras: A socio-climate data linked analysis. *Environmental Health*, **19** (1), 10. https://doi.org/10.1186/s12940-020-0560-9

281. U.S. Census Bureau, 2021: Community Resilience Estimates: Thematic Risk Factor (RF). U.S. Department of Commerce, U.S. Census Bureau. https://experience.arcgis.com/experience/b0341fa9b237456c9a9f1758c15cde8d/

282. U.S. Census Bureau, 2023: Selected Population Profile in the United States—2021: ACS 1-Year Estimates Selected Population Profiles. U.S. Department of Commerce, U.S. Census Bureau, accessed April 3, 2023. https://data.census.gov/table?q=united+states&t=716:720:721:722&g=040xx00us04,06,08,32,35,49&y=2021

283. Schwerdtle, P., K. Bowen, and C. McMichael, 2018: The health impacts of climate-related migration. *BMC Medicine*, **16** (1), 1. https://doi.org/10.1186/s12916-017-0981-7

284. White-Newsome, J., S. McCormick, N. Sampson, M. Buxton, M. O'Neill, C. Gronlund, L. Catalano, K. Conlon, and E. Parker, 2014: Strategies to reduce the harmful effects of extreme heat events: A four-city study. *International Journal of Environmental Research and Public Health*, **11** (2), 1960–1988. https://doi.org/10.3390/ijerph110201960

285. NCEH, 2015: CDC's Building Resilience Against Climate Effects (BRACE) Framework. Centers for Disease Control and Prevention, National Center for Environmental Health. https://www.cdc.gov/climateandhealth/brace.htm

286. Shortridge, A., W. Walker Vi, D.D. White, M.M. Guardaro, D.M. Hondula, and J.K. Vanos, 2022: HeatReady schools: A novel approach to enhance adaptive capacity to heat through school community experiences, risks, and perceptions. *Climate Risk Management*, **36**, 100437. https://doi.org/10.1016/j.crm.2022.100437

287. ADHS, 2021: Managing Extreme Heat Recommendations for Schools: Pilot Version. Arizona Department of Health Services, Phoenix, AZ. https://www.azdhs.gov/documents/preparedness/epidemiology-disease-control/extreme-weather/heat/managing-extreme-heat-recommendations-for-schools.pdf

288. NCEH, 2020: Preparing for the Regional Health Impacts of Climate Change in the United States: A Summary of Health Effects, Resources, and Adaptation Examples from Health Departments Funded by CDC's Climate and Health Program. Centers for Disease Control and Prevention, National Center for Environmental Health. https://stacks.cdc.gov/view/cdc/99147

289. Rosenthal, N., T. Benmarhnia, R. Ahmadov, E. James, and M.E. Marlier, 2022: Population co-exposure to extreme heat and wildfire smoke pollution in California during 2020. *Environmental Research: Climate*, **1** (2), 025004. https://doi.org/10.1088/2752-5295/ac860e

290. Stowell, J.D., C.-E. Yang, J.S. Fu, N.C. Scovronick, M.J. Strickland, and Y. Liu, 2022: Asthma exacerbation due to climate change-induced wildfire smoke in the western US. *Environmental Research Letters*, **17** (1), 014023. https://doi.org/10.1088/1748-9326/ac4138

291. The World Bank, 2021: Enabling Private Investment in Climate Adaptation & Resilience. World Bank Group. https://openknowledge.worldbank.org/server/api/core/bitstreams/127de8c7-d367-59ac-9e54-27ee52c744aa/content

292. CDI, 2023: Climate Risk Carbon Initiative. California Department of Insurance. https://www.insurance.ca.gov/0250-insurers/0300-insurers/0100-applications/ci/

293. Margolis, E.Q., C.H. Guiterman, R.D. Chavardès, J.D. Coop, K. Copes-Gerbitz, D.A. Dawe, D.A. Falk, J.D. Johnston, E. Larson, H. Li, J.M. Marschall, C.E. Naficy, A.T. Naito, M.-A. Parisien, S.A. Parks, J. Portier, H.M. Poulos, K.M. Robertson, J.H. Speer, M. Stambaugh, T.W. Swetnam, A.J. Tepley, I. Thapa, C.D. Allen, Y. Bergeron, L.D. Daniels, P.Z. Fulé, D. Gervais, M.P. Girardin, G.L. Harley, J.E. Harvey, K.M. Hoffman, J.M. Huffman, M.D. Hurteau, L.B. Johnson, C.W. Lafon, M.K. Lopez, R.S. Maxwell, J. Meunier, M. North, M.T. Rother, M.R. Schmidt, R.L. Sherriff, L.A. Stachowiak, A. Taylor, E.J. Taylor, V. Trouet, M.L. Villarreal, L.L. Yocom, K.B. Arabas, A.H. Arizpe, D. Arseneault, A.A. Tarancón, C. Baisan, E. Bigio, F. Biondi, G.D. Cahalan, A. Caprio, J. Cerano-Paredes, B.M. Collins, D.C. Dey, I. Drobyshev, C. Farris, M.A. Fenwick, W. Flatley, M.L. Floyd, Z.e. Gedalof, A. Holz, L.F. Howard, D.W. Huffman, J. Iniguez, K.F. Kipfmueller, S.G. Kitchen, K. Lombardo, D. McKenzie, A.G. Merschel, K.L. Metlen, J. Minor, C.D. O'Connor, L. Platt, W.J. Platt, T. Saladyga, A.B. Stan, S. Stephens, C. Sutheimer, R. Touchan, and P.J. Weisberg, 2022: The North American tree-ring fire-scar network. *Ecosphere*, **13** (7), e4159. https://doi.org/10.1002/ecs2.4159

294. Guiterman, C.H., R.M. Gregg, L.A.E. Marshall, J.J. Beckmann, P.J. van Mantgem, D.A. Falk, J.E. Keeley, A.C. Caprio, J.D. Coop, P.J. Fornwalt, C. Haffey, R.K. Hagmann, S.T. Jackson, A.M. Lynch, E.Q. Margolis, C. Marks, M.D. Meyer, H. Safford, A.D. Syphard, A. Taylor, C. Wilcox, D. Carril, C.A.F. Enquist, D. Huffman, J. Iniguez, N.A. Molinari, C. Restaino, and J.T. Stevens, 2022: Vegetation type conversion in the US Southwest: Frontline observations and management responses. *Fire Ecology*, **18** (1), 6. https://doi.org/10.1186/s42408-022-00131-w

295. Hagmann, R.K., P.F. Hessburg, S.J. Prichard, N.A. Povak, P.M. Brown, P.Z. Fulé, R.E. Keane, E.E. Knapp, J.M. Lydersen, K.L. Metlen, M.J. Reilly, A.J. Sánchez Meador, S.L. Stephens, J.T. Stevens, A.H. Taylor, L.L. Yocom, M.A. Battaglia, D.J. Churchill, L.D. Daniels, D.A. Falk, P. Henson, J.D. Johnston, M.A. Krawchuk, C.R. Levine, G.W. Meigs, A.G. Merschel, M.P. North, H.D. Safford, T.W. Swetnam, and A.E.M. Waltz, 2021: Evidence for widespread changes in the structure, composition, and fire regimes of western North American forests. *Ecological Applications*, **31** (8), e02431. https://doi.org/10.1002/eap.2431

296. Lake, F.K., J. Parrotta, C.P. Giardina, I. Davidson-Hunt, and Y. Uprety, 2018: Ch. 12. Integration of Traditional and Western knowledge in forest landscape restoration. In: *Forest Landscape Restoration: Integrated Approaches to Support Effective Implementation*. Mansourian, S. and J. Parrotta, Eds. Routledge, New York, 198–226. https://www.fs.usda.gov/treesearch/pubs/57158

297. Collins, L., H. Clarke, M.F. Clarke, S.C. McColl Gausden, R.H. Nolan, T. Penman, and R. Bradstock, 2022: Warmer and drier conditions have increased the potential for large and severe fire seasons across south-eastern Australia. *Global Ecology and Biogeography*, **31** (10), 1933–1948. https://doi.org/10.1111/geb.13514

298. Coop, J.D., S.A. Parks, C.S. Stevens-Rumann, S.D. Crausbay, P.E. Higuera, M.D. Hurteau, A. Tepley, E. Whitman, T. Assal, B.M. Collins, K.T. Davis, S. Dobrowski, D.A. Falk, P.J. Fornwalt, P.Z. Fulé, B.J. Harvey, V.R. Kane, C.E. Littlefield, E.Q. Margolis, M. North, M.-A. Parisien, S. Prichard, and K.C. Rodman, 2020: Wildfire-driven forest conversion in western North American landscapes. *BioScience*, **70** (8), 659–673. https://doi.org/10.1093/biosci/biaa061

299. North, M.P., R.E. Tompkins, A.A. Bernal, B.M. Collins, S.L. Stephens, and R.A. York, 2022: Operational resilience in western US frequent-fire forests. *Forest Ecology and Management*, **507**, 120004. https://doi.org/10.1016/j.foreco.2021.120004

300. Prichard, S.J., P.F. Hessburg, R.K. Hagmann, N.A. Povak, S.Z. Dobrowski, M.D. Hurteau, V.R. Kane, R.E. Keane, L.N. Kobziar, C.A. Kolden, M. North, S.A. Parks, H.D. Safford, J.T. Stevens, L.L. Yocom, D.J. Churchill, R.W. Gray, D.W. Huffman, F.K. Lake, and P. Khatri-Chhetri, 2021: Adapting western North American forests to climate change and wildfires: 10 common questions. *Ecological Applications*, **31** (8), e02433. https://doi.org/10.1002/eap.2433

301. MacDonald, G., T. Wall, C.A.F. Enquist, S.R. LeRoy, J.B. Bradford, D.D. Breshears, T. Brown, D. Cayan, C. Dong, D.A. Falk, E. Fleishman, A. Gershunov, M. Hunter, R.A. Loehman, P.J. van Mantgem, B.R. Middleton, H.D. Safford, M.W. Schwartz, and V. Trouet, 2023: Drivers of California's changing wildfires: A state-of-the-knowledge synthesis. *International Journal of Wildland Fire*, **32** (7), 1039–1058. https://doi.org/10.1071/WF22155

302. Westerling, A.L., 2016: Increasing western US forest wildfire activity: Sensitivity to changes in the timing of spring. *Philosophical Transactions of the Royal Society B: Biological Sciences*, **371** (1696), 20150178. https://doi.org/10.1098/rstb.2015.0178

303. Westerling, A.L., H.G. Hidalgo, D.R. Cayan, and T.W. Swetnam, 2006: Warming and earlier spring increase western U.S. forest wildfire activity. *Science*, **313** (5789), 940–943. https://doi.org/10.1126/science.1128834

304. CalFire, 2021: Top 20 Deadliest California Wildfires. California Department of Forestry and Fire Protection. https://www.fire.ca.gov/our-impact/statistics

305. NICC, 2021: Wildland Fire Summary and Statistics Annual Report 2020. National Interagency Coordination Center. https://www.predictiveservices.nifc.gov/intelligence/intelligence.htm

306. NICC, 2022: Wildland Fire Summary and Statistics Annual Report 2021. National Interagency Coordination Center. https://www.predictiveservices.nifc.gov/intelligence/intelligence.htm

307. Stinnesbeck, J., 2020: Wildfires in Nevada: An Overview. Legislative Counsel Bureau, Research Division, 5 pp. https://www.leg.state.nv.us/division/research/documents/wildfires-in-nevada-2020-final.pdf

308. Li, Z., J.P. Angerer, and X.B. Wu, 2021: Temporal patterns of large wildfires and their burn severity in rangelands of western United States. *Geophysical Research Letters*, **48** (7), e2020GL091636. https://doi.org/10.1029/2020GL091636

309. Archer, D., D. Toledo, D.M. Blumenthal, J. Derner, C. Boyd, K. Davies, E. Hamerlynck, R. Sheley, P. Clark, S. Hardegree, F. Pierson, C. Clements, B. Newingham, B. Rector, J. Gaskin, C.L. Wonkka, K. Jensen, T. Monaco, L.T. Vermeire, and S.L. Young, 2023: Invasive annual grasses—Reenvisioning approaches in a changing climate. *Journal of Soil and Water Conservation*, **78** (2), 95–103. https://doi.org/10.2489/jswc.2023.00074

310. Singleton, M.P., A.E. Thode, A.J. Sánchez Meador, and J.M. Iniguez, 2019: Increasing trends in high-severity fire in the southwestern USA from 1984 to 2015. *Forest Ecology and Management*, **433**, 709–719. https://doi.org/10.1016/j.foreco.2018.11.039

311. Haffey, C., T.D. Sisk, C.D. Allen, A.E. Thode, and E.Q. Margolis, 2018: Limits to ponderosa pine regeneration following large high-severity forest fires in the United States Southwest. *Fire Ecology*, **14** (1), 143–163. https://doi.org/10.4996/fireecology.140114316

312. Webb, A.D., D.A. Falk, and D.M. Finch, 2019: Fire Ecology and Management in Lowland Riparian Ecosystems of the Southwestern United States and Northern Mexico. Gen. Tech. Rep. RMRS-GTR-401. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO, 132 pp. https://www.fs.usda.gov/research/treesearch/59156

313. Davis, K.T., S.Z. Dobrowski, P.E. Higuera, Z.A. Holden, T.T. Veblen, M.T. Rother, S.A. Parks, A. Sala, and M.P. Maneta, 2019: Wildfires and climate change push low-elevation forests across a critical climate threshold for tree regeneration. *Proceedings of the National Academy of Sciences of the United States of America*, **116** (13), 6193–6198. https://doi.org/10.1073/pnas.1815107116

314. O'Connor, R.C., M.J. Germino, D.M. Barnard, C.M. Andrews, J.B. Bradford, D.S. Pilliod, R.S. Arkle, and R.K. Shriver, 2020: Small-scale water deficits after wildfires create long-lasting ecological impacts. *Environmental Research Letters*, **15** (4), 044001. https://doi.org/10.1088/1748-9326/ab79e4

315. Rodman, K.C., T.T. Veblen, M.A. Battaglia, M.E. Chambers, P.J. Fornwalt, Z.A. Holden, T.E. Kolb, J.R. Ouzts, and M.T. Rother, 2020: A changing climate is snuffing out post-fire recovery in montane forests. *Global Ecology and Biogeography*, **29** (11), 2039–2051. https://doi.org/10.1111/geb.13174

316. Parks, S.A., S.Z. Dobrowski, J.D. Shaw, and C. Miller, 2019: Living on the edge: Trailing edge forests at risk of fire-facilitated conversion to non-forest. *Ecosphere*, **10** (3), e02651. https://doi.org/10.1002/ecs2.2651

317. Halofsky, J.E., D.L. Peterson, and B.J. Harvey, 2020: Changing wildfire, changing forests: The effects of climate change on fire regimes and vegetation in the Pacific Northwest, USA. *Fire Ecology*, **16** (1), 4. https://doi.org/10.1186/s42408-019-0062-8

318. Keeley, J.E. and A.D. Syphard, 2019: Twenty-first century California, USA, wildfires: Fuel-dominated vs. wind-dominated fires. *Fire Ecology*, **15** (1), 24. https://doi.org/10.1186/s42408-019-0041-0

319. Loehman, R.A., R.E. Keane, and L.M. Holsinger, 2020: Simulation modeling of complex climate, wildfire, and vegetation dynamics to address wicked problems in land management. *Frontiers in Forests and Global Change*, **3**, 3. https://doi.org/10.3389/ffgc.2020.00003

320. Stevens-Rumann, C.S., K.B. Kemp, P.E. Higuera, B.J. Harvey, M.T. Rother, D.C. Donato, P. Morgan, and T.T. Veblen, 2018: Evidence for declining forest resilience to wildfires under climate change. *Ecology Letters*, **21** (2), 243–252. https://doi.org/10.1111/ele.12889

321. Stevens-Rumann, C.S. and P. Morgan, 2019: Tree regeneration following wildfires in the western US: A review. *Fire Ecology*, **15** (1), 15. https://doi.org/10.1186/s42408-019-0032-1

322. Turner, M.G., K.H. Braziunas, W.D. Hansen, and B.J. Harvey, 2019: Short-interval severe fire erodes the resilience of subalpine lodgepole pine forests. *Proceedings of the National Academy of Sciences of the United States of America*, **116** (23), 11319–11328. https://doi.org/10.1073/pnas.1902841116

323. Doherty, K., D.M. Theobald, J.B. Bradford, L.A. Wiechman, G. Bedrosian, C.S. Boyd, M. Cahill, P.S. Coates, M.K. Creutzburg, M.R. Crist, S.P. Finn, A.V. Kumar, C.E. Littlefield, J.D. Maestas, K.L. Prentice, B.G. Prochazka, T.E. Remington, W.D. Sparklin, J.C. Tull, Z. Wurtzebach, and K.A. Zeller, 2022: A Sagebrush Conservation Design to Proactively Restore America's Sagebrush Biome. Open-File Report 2022–1081. U.S. Geological Survey. https://www.usgs.gov/publications/a-sagebrush-conservation-design-proactively-restore-americas-sagebrush-biome

324. Shinneman, D.J., E.K. Strand, M. Pellant, J.T. Abatzoglou, M.W. Brunson, N.F. Glenn, J.A. Heinrichs, M. Sadegh, and N.M. Vaillant, 2023: Future direction of fuels management in sagebrush rangelands. *Rangeland Ecology & Management*, **86**, 50–63. https://doi.org/10.1016/j.rama.2022.10.009

325. Felton, A.J., R.K. Shriver, M. Stemkovski, J.B. Bradford, K.N. Suding, and P.B. Adler, 2022: Climate disequilibrium dominates uncertainty in long-term projections of primary productivity. *Ecology Letters*, **25** (12), 2688–2698. https://doi.org/10.1111/ele.14132

326. Ellis, T.M., D.M.J.S. Bowman, P. Jain, M.D. Flannigan, and G.J. Williamson, 2022: Global increase in wildfire risk due to climate-driven declines in fuel moisture. *Global Change Biology*, **28** (4), 1544–1559. https://doi.org/10.1111/gcb.16006

327. Haynes, K., K. Short, G. Xanthopoulos, D. Viegas, L.M. Ribeiro, and R. Blanchi, 2020: Wildfires and WUI fire fatalities. In: *Encyclopedia of Wildfires and Wildland-Urban Interface (WUI) Fires*. Manzello, S.L., Ed. Springer, Cham, Switzerland, 1–16. https://doi.org/10.1007/978-3-319-51727-8_92-1

328. Schwarz, L., A. Dimitrova, R. Aguilera, R. Basu, A. Gershunov, and T. Benmarhnia, 2022: Smoke and COVID-19 case fatality ratios during California wildfires. *Environmental Research Letters*, **17** (1), 014054. https://doi.org/10.1088/1748-9326/ac4538

329. Tiwari, B., B. Ajmera, A. Gonzalez, and H. Sonbol, 2020: Impact of wildfire on triggering mudslides—A case study of 2018 Montecito debris flows. In: *Geo-Congress 2020: Engineering, Monitoring, and Management of Geotechnical Infrastructure*. Hambleton, J.P., R. Makhnenko, and A.S. Budge, Eds. American Society of Civil Engineers, Reston, VA, 40–49. https://doi.org/10.1061/9780784482797.005

330. Murray, A.T., L. Carvalho, R.L. Church, C. Jones, D. Roberts, J. Xu, K. Zigner, and D. Nash, 2021: Coastal vulnerability under extreme weather. *Applied Spatial Analysis and Policy*, **14** (3), 497–523. https://doi.org/10.1007/s12061-020-09357-0

331. Radeloff, V.C., D.P. Helmers, H.A. Kramer, M.H. Mockrin, P.M. Alexandre, A. Bar-Massada, V. Butsic, T.J. Hawbaker, S. Martinuzzi, A.D. Syphard, and S.I. Stewart, 2018: Rapid growth of the US wildland-urban interface raises wildfire risk. *Proceedings of the National Academy of Sciences of the United States of America*, **115** (13), 3314–3319. https://doi.org/10.1073/pnas.1718850115

332. Rao, K., A.P. Williams, N.S. Diffenbaugh, M. Yebra, and A.G. Konings, 2022: Plant-water sensitivity regulates wildfire vulnerability. *Nature Ecology & Evolution*, **6** (3), 332–339. https://doi.org/10.1038/s41559-021-01654-2

333. Zhuang, Y., R. Fu, B.D. Santer, R.E. Dickinson, and A. Hall, 2021: Quantifying contributions of natural variability and anthropogenic forcings on increased fire weather risk over the western United States. *Proceedings of the National Academy of Sciences of the United States of America*, **118** (45), e2111875118. https://doi.org/10.1073/pnas.2111875118

334. Winkler, R.L. and M.D. Rouleau, 2021: Amenities or disamenities? Estimating the impacts of extreme heat and wildfire on domestic US migration. *Population and Environment*, **42** (4), 622–648. https://doi.org/10.1007/s11111-020-00364-4

335. Sharygin, E., 2021: Ch. 3. Estimating migration impacts of wildfire: California's 2017 North Bay fires. In: *The Demography of Disasters: Impacts for Population and Place*. Karácsonyi, D., A. Taylor, and D. Bird, Eds. Springer, Cham, Switzerland, 49–70. https://doi.org/10.1007/978-3-030-49920-4_3

336. Baijnath-Rodino, J.A., M. Kumar, M. Rivera, K.D. Tran, and T. Banerjee, 2021: How vulnerable are American states to wildfires? A livelihood vulnerability assessment. *Fire*, **4** (3), 54. https://doi.org/10.3390/fire4030054

337. Goldsmith, L., V. Raditz, and M. Méndez, 2022: Queer and present danger: Understanding the disparate impacts of disasters on LGBTQ+ communities. *Disasters*, **46** (4), 946–973. https://doi.org/10.1111/disa.12509

338. Davies, I.P., R.D. Haugo, J.C. Robertson, and P.S. Levin, 2018: The unequal vulnerability of communities of color to wildfire. *PLoS ONE*, **13** (11), 0205825. https://doi.org/10.1371/journal.pone.0205825

339. Engelman, A., L. Craig, and A. Iles, 2022: Global disability justice in climate disasters: Mobilizing people with disabilities as change agents. *Health Affairs*, **41** (10), 1496–1504. https://doi.org/10.1377/hlthaff.2022.00474

340. Madhusoodanan, J., 2021: Wildfires pose a burning problem for wines and winemakers. *Proceedings of the National Academy of Sciences of the United States of America*, **118** (34), e2113327118. https://doi.org/10.1073/pnas.2113327118

341. Cartier, E.A. and L.L. Taylor, 2020: Living in a wildfire: The relationship between crisis management and community resilience in a tourism-based destination. *Tourism Management Perspectives*, **34**, 100635. https://doi.org/10.1016/j.tmp.2020.100635

342. Kim, M.-K. and P.M. Jakus, 2019: Wildfire, national park visitation, and changes in regional economic activity. *Journal of Outdoor Recreation and Tourism*, **26**, 34–42. https://doi.org/10.1016/j.jort.2019.03.007

343. Dillis, C., V. Butsic, D. Moanga, P. Parker-Shames, A. Wartenberg, and T.E. Grantham, 2022: The threat of wildfire is unique to cannabis among agricultural sectors in California. *Ecosphere*, **13** (9), e4205. https://doi.org/10.1002/ecs2.4205

344. Crews, P., P. Dorenbach, G. Amberchan, R.F. Keiffer, I. Lizama-Chamu, T.C. Ruthenburg, E.P. McCauley, and G. McGourty, 2022: Natural product phenolic diglycosides created from wildfires, defining their impact on California and Oregon grapes and wines. *Journal of Natural Products*, **85** (3), 547–561. https://doi.org/10.1021/acs.jnatprod.2c00028

345. Rhoades, C.C., J.P. Nunes, U. Silins, and S.H. Doerr, 2019: The influence of wildfire on water quality and watershed processes: New insights and remaining challenges. *International Journal of Wildland Fire*, **28** (10), 721–725. https://doi.org/10.1071/wfv28n10_fo

346. Carbone, L.M., J. Tavella, J.G. Pausas, and R. Aguilar, 2019: A global synthesis of fire effects on pollinators. *Global Ecology and Biogeography*, **28** (10), 1487–1498. https://doi.org/10.1111/geb.12939

347. O'Hara, K.C., J. Ranches, L.M. Roche, T.K. Schohr, R.C. Busch, and G.U. Maier, 2021: Impacts from wildfires on livestock health and production: Producer perspectives. *Animals*, **11** (11), 3230. https://doi.org/10.3390/ani11113230

348. Gellman, J., M. Walls, and M. Wibbenmeyer, 2022: Wildfire, smoke, and outdoor recreation in the western United States. *Forest Policy and Economics*, **134**, 102619. https://doi.org/10.1016/j.forpol.2021.102619

349. Vukomanovic, J. and T. Steelman, 2019: A systematic review of relationships between mountain wildfire and ecosystem services. *Landscape Ecology*, **34** (5), 1179–1194. https://doi.org/10.1007/s10980-019-00832-9

350. Hohner, A.K., C.C. Rhoades, P. Wilkerson, and F.L. Rosario-Ortiz, 2019: Wildfires alter forest watersheds and threaten drinking water quality. *Accounts of Chemical Research*, **52** (5), 1234–1244. https://doi.org/10.1021/acs.accounts.8b00670

351. Schulze, S.S., E.C. Fischer, S. Hamideh, and H. Mahmoud, 2020: Wildfire impacts on schools and hospitals following the 2018 California Camp Fire. *Natural Hazards*, **104** (1), 901–925. https://doi.org/10.1007/s11069-020-04197-0

352. Robinne, F.-N., D.W. Hallema, K.D. Bladon, M.D. Flannigan, G. Boisramé, C.M. Bréthaut, S.H. Doerr, G. Di Baldassarre, L.A. Gallagher, A.K. Hohner, S.J. Khan, A.M. Kinoshita, R. Mordecai, J.P. Nunes, P. Nyman, C. Santín, G. Sheridan, C.R. Stoof, M.P. Thompson, J.M. Waddington, and Y. Wei, 2021: Scientists' warning on extreme wildfire risks to water supply. *Hydrological Processes*, **35** (5), e14086. https://doi.org/10.1002/hyp.14086

353. Juliano, T.W., P.A. Jiménez, B. Kosović, T. Eidhammer, G. Thompson, L.K. Berg, J. Fast, A. Motley, and A. Polidori, 2022: Smoke from 2020 United States wildfires responsible for substantial solar energy forecast errors. *Environmental Research Letters*, **17** (3), 034010. https://doi.org/10.1088/1748-9326/ac5143

354. Pereira, P., I. Bogunovic, W. Zhao, and D. Barcelo, 2021: Short-term effect of wildfires and prescribed fires on ecosystem services. *Current Opinion in Environmental Science & Health*, **22**, 100266. https://doi.org/10.1016/j.coesh.2021.100266

355. van Mantgem, P.J., A.C. Caprio, N.L. Stephenson, and A.J. Das, 2021: Forest resistance to extended drought enhanced by prescribed fire in low elevation forests of the Sierra Nevada. *Forests*, **12** (9), 1248. https://doi.org/10.3390/f12091248

356. Hunter, M.E. and M.D. Robles, 2020: Tamm review: The effects of prescribed fire on wildfire regimes and impacts: A framework for comparison. *Forest Ecology and Management*, **475**, 118435. https://doi.org/10.1016/j.foreco.2020.118435

357. Long, J.W., F.K. Lake, R.W. Goode, and B.M. Burnette, 2020: How traditional tribal perspectives influence ecosystem restoration. *Ecopsychology*, **12** (2). https://doi.org/10.1089/eco.2019.0055

358. Banerjee, T., 2020: Impacts of forest thinning on wildland fire behavior. *Forests*, **11** (9), 918. https://doi.org/10.3390/f11090918

359. Goodwin, M.J., M.P. North, H.S.J. Zald, and M.D. Hurteau, 2020: Changing climate reallocates the carbon debt of frequent-fire forests. *Global Change Biology*, **26** (11), 6180–6189. https://doi.org/10.1111/gcb.15318

360. Stephens, S.L., M.A. Battaglia, D.J. Churchill, B.M. Collins, M. Coppoletta, C.M. Hoffman, J.M. Lydersen, M.P. North, R.A. Parsons, S.M. Ritter, and J.T. Stevens, 2021: Forest restoration and fuels reduction: Convergent or divergent? *BioScience*, **71** (1), 85–101. https://doi.org/10.1093/biosci/biaa134

361. Striplin, R., S.A. McAfee, H.D. Safford, and M.J. Papa, 2020: Retrospective analysis of burn windows for fire and fuels management: An example from the Lake Tahoe Basin, California, USA. *Fire Ecology*, **16** (1), 13. https://doi.org/10.1186/s42408-020-00071-3

362. Sleeter, B.M., D.C. Marvin, D.R. Cameron, P.C. Selmants, A.L. Westerling, J. Kreitler, C.J. Daniel, J. Liu, and T.S. Wilson, 2019: Effects of 21st-century climate, land use, and disturbances on ecosystem carbon balance in California. *Global Change Biology*, **25** (10), 3334–3353. https://doi.org/10.1111/gcb.14677

363. Xu, X., A. Huang, E. Belle, P. De Frenne, and G. Jia, 2022: Protected areas provide thermal buffer against climate change. *Science Advances*, **8** (44), 0119. https://doi.org/10.1126/sciadv.abo0119

364. Anderegg, W.R.L., A.T. Trugman, G. Badgley, C.M. Anderson, A. Bartuska, P. Ciais, D. Cullenward, C.B. Field, J. Freeman, S.J. Goetz, J.A. Hicke, D. Huntzinger, R.B. Jackson, J. Nickerson, S. Pacala, and J.T. Randerson, 2020: Climate-driven risks to the climate mitigation potential of forests. *Science*, **368** (6497), 7005. https://doi.org/10.1126/science.aaz7005

365. Ontl, T.A., M.K. Janowiak, C.W. Swanston, J. Daley, S. Handler, M. Cornett, S. Hagenbuch, C. Handrick, L. McCarthy, and N. Patch, 2020: Forest management for carbon sequestration and climate adaptation. *Journal of Forestry*, **118** (1), 86–101. https://doi.org/10.1093/jofore/fvz062

366. Krofcheck, D.J., C.C. Remy, A.R. Keyser, and M.D. Hurteau, 2019: Optimizing forest management stabilizes carbon under projected climate and wildfires. *Journal of Geophysical Research: Biogeosciences*, **124** (10), 3075–3087. https://doi.org/10.1029/2019jg005206

367. North, M.P., J.T. Stevens, D.F. Greene, M. Coppoletta, E.E. Knapp, A.M. Latimer, C.M. Restaino, R.E. Tompkins, K.R. Welch, R.A. York, D.J.N. Young, J.N. Axelson, T.N. Buckley, B.L. Estes, R.N. Hager, J.W. Long, M.D. Meyer, S.M. Ostoja, H.D. Safford, K.L. Shive, C.L. Tubbesing, H. Vice, D. Walsh, C.M. Werner, and P. Wyrsch, 2019: Tamm review: Reforestation for resilience in dry western U.S. forests. *Forest Ecology and Management*, **432**, 209–224. https://doi.org/10.1016/j.foreco.2018.09.007

368. Holl, K.D. and P.H.S. Brancalion, 2020: Tree planting is not a simple solution. *Science*, **368** (6491), 580–581. https://doi.org/10.1126/science.aba8232

369. Anderson, R., P.E. Bayer, and D. Edwards, 2020: Climate change and the need for agricultural adaptation. *Current Opinion in Plant Biology*, **56**, 197–202. https://doi.org/10.1016/j.pbi.2019.12.006

370. Meyer, M.D., B.L. Estes, A. Wuenschel, B. Bulaon, A. Stucy, D.F. Smith, and A.C. Caprio, 2019: Structure, diversity and health of Sierra Nevada red fir forests with reestablished fire regimes. *International Journal of Wildland Fire*, **28** (5), 386–396. https://doi.org/10.1071/wf18114

371. Mildenberger, M., P.D. Howe, S. Trachtman, L.C. Stokes, and M. Lubell, 2022: The effect of public safety power shut-offs on climate change attitudes and behavioural intentions. *Nature Energy*, **7** (8), 736–743. https://doi.org/10.1038/s41560-022-01071-0

372. Zanocco, C., J. Flora, R. Rajagopal, and H. Boudet, 2021: When the lights go out: Californians' experience with wildfire-related public safety power shutoffs increases intention to adopt solar and storage. *Energy Research & Social Science*, **79**, 102183. https://doi.org/10.1016/j.erss.2021.102183

373. Mildenberger, M., S. Trachtman, P. Howe, L. Stokes, and M. Lubell, 2021: Wildfire-mitigating power shut-offs promote household-level adaptation but not climate policy support. *Nature Portfolio*. https://doi.org/10.21203/rs.3.rs-631250/v1

374. Wong-Parodi, G., 2020: When climate change adaptation becomes a "looming threat" to society: Exploring views and responses to California wildfires and public safety power shutoffs. *Energy Research & Social Science*, **70**, 101757. https://doi.org/10.1016/j.erss.2020.101757

375. Martin, J.T., G.T. Pederson, C.A. Woodhouse, E.R. Cook, G.J. McCabe, K.J. Anchukaitis, E.K. Wise, P.J. Erger, L. Dolan, M. McGuire, S. Gangopadhyay, K.J. Chase, J.S. Littell, S.T. Gray, S. St. George, J.M. Friedman, D.J. Sauchyn, J.-M. St-Jacques, and J. King, 2020: Increased drought severity tracks warming in the United States' largest river basin. *Proceedings of the National Academy of Sciences of the United States of America*, **117** (21), 11328–11336. https://doi.org/10.1073/pnas.1916208117

376. Luo, X., S. Dee, S. Stevenson, Y. Okumura, N. Steiger, and L. Parsons, 2022: Last millennium ENSO diversity and North American teleconnections: New insights from paleoclimate data assimilation. *Paleoceanography and Paleoclimatology*, **37** (3), e2021PA004283. https://doi.org/10.1029/2021pa004283

377. Patricola, C.M., J.P. O'Brien, M.D. Risser, A.M. Rhoades, T.A. O'Brien, P.A. Ullrich, D.A. Stone, and W.D. Collins, 2020: Maximizing ENSO as a source of western US hydroclimate predictability. *Climate Dynamics*, **54** (1), 351–372. https://doi.org/10.1007/s00382-019-05004-8

378. Brown, T.C., V. Mahat, and J.A. Ramirez, 2019: Adaptation to future water shortages in the United States caused by population growth and climate change. *Earth's Future*, **7** (3), 219–234. https://doi.org/10.1029/2018ef001091

379. Di Baldassarre, G., N. Wanders, A. AghaKouchak, L. Kuil, S. Rangecroft, T.I.E. Veldkamp, M. Garcia, P.R. van Oel, K. Breinl, and A.F. Van Loon, 2018: Water shortages worsened by reservoir effects. *Nature Sustainability*, **1** (11), 617–622. https://doi.org/10.1038/s41893-018-0159-0

380. Elias, E., J. Reyes, C. Steele, and A. Rango, 2018: Diverse landscapes, diverse risks: Synthesis of the special issue on climate change and adaptive capacity in a hotter, drier Southwestern United States. *Climatic Change*, **148** (3), 339–353. https://doi.org/10.1007/s10584-018-2219-x

381. Zhang, F., J.A. Biederman, M.P. Dannenberg, D. Yan, S.C. Reed, and W.K. Smith, 2021: Five decades of observed daily precipitation reveal longer and more variable drought events across much of the western United States. *Geophysical Research Letters*, **48** (7), e2020GL092293. https://doi.org/10.1029/2020gl092293

382. du Bray, M.V., B. Quimby, J.C. Bausch, A. Wutich, W.M. Eaton, K.J. Brasier, A. Brewis, and C. Williams, 2022: Red, white, and blue: Environmental distress among water stakeholders in a U.S. farming community. *Weather, Climate, and Society*, **14** (2), 585–595. https://doi.org/10.1175/wcas-d-21-0103.1

383. Wilson, N.J., T. Montoya, R. Arseneault, and A. Curley, 2021: Governing water insecurity: Navigating Indigenous water rights and regulatory politics in settler colonial states. *Water International*, **46** (6), 783–801. https://doi.org/10.1080/02508060.2021.1928972

384. Wutich, A., W. Jepson, C. Velasco, A. Roque, Z. Gu, M. Hanemann, M.J. Hossain, L. Landes, R. Larson, W.W. Li, O. Morales-Pate, N. Patwoary, S. Porter, Y.-s. Tsai, M. Zheng, and P. Westerhoff, 2022: Water insecurity in the Global North: A review of experiences in U.S. colonias communities along the Mexico border. *WIREs Water*, **9** (4), e1595. https://doi.org/10.1002/wat2.1595

385. Laufkötter, C., J. Zscheischler, and T.L. Frölicher, 2020: High-impact marine heatwaves attributable to human-induced global warming. *Science*, **369** (6511), 1621–1625. https://doi.org/10.1126/science.aba0690

386. Orr, J.A., R.D. Vinebrooke, M.C. Jackson, K.J. Kroeker, R.L. Kordas, C. Mantyka-Pringle, P.J. Van den Brink, F. De Laender, R. Stoks, M. Holmstrup, C.D. Matthaei, W.A. Monk, M.R. Penk, S. Leuzinger, R.B. Schäfer, and J.J. Piggott, 2020: Towards a unified study of multiple stressors: Divisions and common goals across research disciplines. *Proceedings of the Royal Society B: Biological Sciences*, **287** (1926), 20200421. https://doi.org/10.1098/rspb.2020.0421

387. Sunday, J.M., E. Howard, S. Siedlecki, D.J. Pilcher, C. Deutsch, P. MacCready, J. Newton, and T. Klinger, 2022: Biological sensitivities to high-resolution climate change projections in the California Current Marine Ecosystem. *Global Change Biology*, **28** (19), 5726–5740. https://doi.org/10.1111/gcb.16317

388. National Academies of Sciences, Engineering, and Medicine, 2022: *A Research Strategy for Ocean-based Carbon Dioxide Removal and Sequestration*. The National Academies Press, Washington, DC, 322 pp. https://doi.org/10.17226/26278

389. DeAngelo, J., B.T. Saenz, I.B. Arzeno-Soltero, C.A. Frieder, M.C. Long, J. Hamman, K.A. Davis, and S.J. Davis, 2023: Economic and biophysical limits to seaweed farming for climate change mitigation. *Nature Plants*, **9** (1), 45–57. https://doi.org/10.1038/s41477-022-01305-9

390. Levin, L.A., J.M. Alfaro-Lucas, A. Colaço, E.E. Cordes, N. Craik, R. Danovaro, H.-J. Hoving, J. Ingels, N.C. Mestre, S. Seabrook, A.R. Thurber, C. Vivian, and M. Yasuhara, 2023: Deep-sea impacts of climate interventions. *Science*, **379** (6636), 978–981. https://doi.org/10.1126/science.ade7521

391. Spillias, S., R. Kelly, R.S. Cottrell, K.R. O'Brien, R.-Y. Im, J.Y. Kim, C. Lei, R.W.S. Leung, M. Matsuba, J.A. Reis, Y. Sato, K. Sempert, and E. McDonald-Madden, 2023: The empirical evidence for the social-ecological impacts of seaweed farming. *PLOS Sustainability and Transformation*, **2** (2), e0000042. https://doi.org/10.1371/journal.pstr.0000042

392. Gobler, C.J., 2020: Climate change and harmful algal blooms: Insights and perspective. *Harmful Algae*, **91**, 101731. https://doi.org/10.1016/j.hal.2019.101731

393. Sea-Level Rise Leadership Team, 2022: State Agency Sea-Level Rise Action Plan for California. State of California, Ocean Protection Council. https://www.opc.ca.gov/webmaster/_media_library/2022/02/Item-7_Exhibit-A_SLR-Action-Plan-Final.pdf

394. State of California, 2022: Protecting Californians from Extreme Heat: A State Action Plan to Build Community Resilience. State of California. https://resources.ca.gov/-/media/CNRA-Website/Files/Initiatives/Climate-Resilience/2022-Final-Extreme-Heat-Action-Plan.pdf

395. State of California, 2021: California Climate Adaptation Strategy. State of California. https://climateresilience.ca.gov/

396. Governor's Office of Planning and Research, 2022: Climate Adaptation Planning Grant Program. State of California, Governor's Office of Planning and Research. https://opr.ca.gov/climate/icarp/grants/adaptation-planning-grant.html#:~:text=The%20Adaptation%20Planning%20Grant%20Program,infrastructure%20projects%20across%20the%20state

397. Caltrans, 2022: Climate Adaptation Planning—Sustainable Transportation Planning Grant Program. California Department of Transportation. https://www.grants.ca.gov/grants/climate-adaptation-planning-sustainable-transportation-planning-grant-program/

398. California Transportation Commission, 2022: Local Transportation Climate Adaptation Program (LTCAP). State of California, California Transportation Commission. https://catc.ca.gov/programs/local-transportation-climate-adaptation-program

399. Governor's Office of Planning and Research, 2022: Regional Resilience Planning and Implementation Grant Program. State of California, Governor's Office of Planning and Research. https://opr.ca.gov/climate/icarp/grants/regional-resilience-grant.html

400. Lester, S.E., R.R. Gentry, H.R. Lemoine, H.E. Froehlich, L.D. Gardner, M. Rennick, E.O. Ruff, and K.D. Thompson, 2022: Diverse state-level marine aquaculture policy in the United States: Opportunities and barriers for industry development. *Reviews in Aquaculture*, **14** (2), 890–906. https://doi.org/10.1111/raq.12631

401. Froehlich, H.E., J.Z. Koehn, K.K. Holsman, and B.S. Halpern, 2022: Emerging trends in science and news of climate change threats to and adaptation of aquaculture. *Aquaculture*, **549**, 737812. https://doi.org/10.1016/j.aquaculture.2021.737812

402. Williams, A.P., E.R. Cook, J.E. Smerdon, B.I. Cook, J.T. Abatzoglou, K. Bolles, S.H. Baek, A.M. Badger, and B. Livneh, 2020: Large contribution from anthropogenic warming to an emerging North American megadrought. *Science*, **368** (6488), 314–318. https://doi.org/10.1126/science.aaz9600

403. Dannenberg, M.P., D. Yan, M.L. Barnes, W.K. Smith, M.R. Johnston, R.L. Scott, J.A. Biederman, J.F. Knowles, X. Wang, T. Duman, M.E. Litvak, J.S. Kimball, A.P. Williams, and Y. Zhang, 2022: Exceptional heat and atmospheric dryness amplified losses of primary production during the 2020 U.S. Southwest hot drought. *Global Change Biology*, **28** (16), 4794–4806. https://doi.org/10.1111/gcb.16214

404. Robertson, A.D., Y. Zhang, L.A. Sherrod, S.T. Rosenzweig, L. Ma, L. Ahuja, and M.E. Schipanski, 2018: Climate change impacts on yields and soil carbon in row crop dryland agriculture. *Journal of Environmental Quality*, **47** (4), 684–694. https://doi.org/10.2134/jeq2017.08.0309

405. Collier, R.J., L.H. Baumgard, R.B. Zimbelman, and Y. Xiao, 2018: Heat stress: Physiology of acclimation and adaptation. *Animal Frontiers*, **9** (1), 12–19. https://doi.org/10.1093/af/vfy031

406. Klemm, T. and D.D. Briske, 2021: Retrospective assessment of beef cow numbers to climate variability throughout the U.S. Great Plains. *Rangeland Ecology & Management*, **78**, 273–280. https://doi.org/10.1016/j.rama.2019.07.004

407. Schwarz, L., K. Hansen, A. Alari, S.D. Ilango, N. Bernal, R. Basu, A. Gershunov, and T. Benmarhnia, 2021: Spatial variation in the joint effect of extreme heat events and ozone on respiratory hospitalizations in California. *Proceedings of the National Academy of Sciences of the United States of America*, **118** (22), e2023078118. https://doi.org/10.1073/pnas.2023078118

408. Georgescu, M., P.E. Morefield, B.G. Bierwagen, and C.P. Weaver, 2014: Urban adaptation can roll back warming of emerging megapolitan regions. *Proceedings of the National Academy of Sciences of the United States of America*, **111** (8), 2909–2914. https://doi.org/10.1073/pnas.1322280111

409. Hondula, D.M., M. Georgescu, and R.C. Balling, 2014: Challenges associated with projecting urbanization-induced heat-related mortality. *Science of The Total Environment*, **490**, 538–544. https://doi.org/10.1016/j.scitotenv.2014.04.130

410. Burke, M., A. Driscoll, S. Heft-Neal, J. Xue, J. Burney, and M. Wara, 2021: The changing risk and burden of wildfire in the United States. *Proceedings of the National Academy of Sciences of the United States of America*, **118** (2), e2011048118. https://doi.org/10.1073/pnas.2011048118

411. Magzamen, S., R.W. Gan, J. Liu, K. O'Dell, B. Ford, K. Berg, K. Bol, A. Wilson, E.V. Fischer, and J.R. Pierce, 2021: Differential cardiopulmonary health impacts of local and long-range transport of wildfire smoke. *GeoHealth*, **5** (3), 2020GH000330. https://doi.org/10.1029/2020gh000330

412. Hondula, D.M., J.L. Sabo, R. Quay, M. Chester, M. Georgescu, N.B. Grimm, S.L. Harlan, A. Middel, S. Porter, C.L. Redman, B. Rittmann, B.L. Ruddell, and D.D. White, 2019: Cities of the Southwest are testbeds for urban resilience. *Frontiers in Ecology and the Environment*, **17** (2), 79–80. https://doi.org/10.1002/fee.2005

413. Keith, L. and S. Meerow, 2022: Planning for Urban Heat Resilience. PAS Report 600. American Planning Association, 99 pp. https://www.planning.org/publications/report/9245695/

414. Keith, L., S. Meerow, D.M. Hondula, V.K. Turner, and J.C. Arnott, 2021: Deploy heat officers, policies and metrics. *Nature*, **598** (7879), 29–31. https://doi.org/10.1038/d41586-021-02677-2

415. Schramm, P.J., A.L.A. Janabi, L.W. Campbell, J.L. Donatuto, and S.C. Gaughen, 2020: How Indigenous communities are adapting to climate change: Insights from the Climate-Ready Tribes Initiative. *Health Affairs*, **39** (12), 2153–2159. https://doi.org/10.1377/hlthaff.2020.00997

416. OPHDST, 2023: National Notifiable Disease Surveillance System: Notifiable Infectious Disease Tables. Centers for Disease Control and Prevention, Office of Public Health Data, Surveillance, and Technology. https://www.cdc.gov/nndss/data-statistics/infectious-tables/index.html

417. Rochlin, I., A. Faraji, K. Healy, and T.G. Andreadis, 2019: West Nile virus mosquito vectors in North America. *Journal of Medical Entomology*, **56** (6), 1475–1490. https://doi.org/10.1093/jme/tjz146

418. Reisen, W.K., 2012: The contrasting bionomics of *Culex* mosquitoes in western North America. *Journal of the American Mosquito Control Association*, **28** (4s), 82–91. https://doi.org/10.2987/8756-971x-28.4.82

419. Harrigan, R.J., H.A. Thomassen, W. Buermann, and T.B. Smith, 2014: A continental risk assessment of West Nile virus under climate change. *Global Change Biology*, **20** (8), 2417–2425. https://doi.org/10.1111/gcb.12534

420. Habeeb, D., J. Vargo, and B. Stone, 2015: Rising heat wave trends in large US cities. *Natural Hazards*, **76** (3), 1651–1665. https://doi.org/10.1007/s11069-014-1563-z

421. Ebi, K.L., A. Capon, P. Berry, C. Broderick, R. de Dear, G. Havenith, Y. Honda, R.S. Kovats, W. Ma, A. Malik, N.B. Morris, L. Nybo, S.I. Seneviratne, J. Vanos, and O. Jay, 2021: Hot weather and heat extremes: Health risks. *The Lancet*, **398** (10301), 698–708. https://doi.org/10.1016/s0140-6736(21)01208-3

422. Crooks, J.L., W.E. Cascio, M.S. Percy, J. Reyes, L.M. Neas, and E.D. Hilborn, 2016: The association between dust storms and daily non-accidental mortality in the United States, 1993–2005. *Environmental Health Perspectives*, **124** (11), 1735–1743. https://doi.org/10.1289/ehp216

423. Reid, C.E., E.M. Considine, G.L. Watson, D. Telesca, G.G. Pfister, and M. Jerrett, 2019: Associations between respiratory health and ozone and fine particulate matter during a wildfire event. *Environment International*, **129**, 291–298. https://doi.org/10.1016/j.envint.2019.04.033

424. Borlina, C.S. and N.O. Rennó, 2017: The impact of a severe drought on dust lifting in California's Owens Lake area. *Scientific Reports*, **7** (1), 1784. https://doi.org/10.1038/s41598-017-01829-7

425. U.S. Census Bureau, 2022: Foreign Born. U.S. Department of Commerce, U.S. Census Bureau. https://www.census.gov/topics/population/foreign-born.html

426. Reid, C.E. and M.M. Maestas, 2019: Wildfire smoke exposure under climate change: Impact on respiratory health of affected communities. *Current Opinion in Pulmonary Medicine*, **25** (2). https://doi.org/10.1097/mcp.0000000000000552

427. Bekkar, B., S. Pacheco, R. Basu, and N. DeNicola, 2020: Association of air pollution and heat exposure with preterm birth, low birth weight, and stillbirth in the US: A systematic review. JAMA *Network Open*, **3** (6), e208243. https://doi.org/10.1001/jamanetworkopen.2020.8243

428. Benmarhnia, T., J. Huang, R. Basu, J. Wu, and T.A. Bruckner, 2017: Decomposition analysis of Black–White disparities in birth outcomes: The relative contribution of air pollution and social factors in California. *Environmental Health Perspectives*, **125** (10), 107003. https://doi.org/10.1289/ehp490

429. Lowe, A.A., B. Bender, A.H. Liu, T. Solomon, A. Kobernick, W. Morgan, and L.B. Gerald, 2018: Environmental concerns for children with asthma on the Navajo Nation. *Annals of the American Thoracic Society*, **15** (6), 745–753. https://doi.org/10.1513/annalsats.201708-674ps

430. Sun, Y., S.D. Ilango, L. Schwarz, Q. Wang, J.-C. Chen, J.M. Lawrence, J. Wu, and T. Benmarhnia, 2020: Examining the joint effects of heatwaves, air pollution, and green space on the risk of preterm birth in California. *Environmental Research Letters*, **15** (10), 104099. https://doi.org/10.1088/1748-9326/abb8a3

431. USGCRP, 2016: *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment*. Crimmins, A., J. Balbus, J.L. Gamble, C.B. Beard, J.E. Bell, D. Dodgen, R.J. Eisen, N. Fann, M.D. Hawkins, S.C. Herring, L. Jantarasami, D.M. Mills, S. Saha, M.C. Sarofim, J. Trtanj, and L. Ziska, Eds. U.S. Global Change Research Program, Washington, DC, 312 pp. https://doi.org/10.7930/j0r49nqx

432. Ebi, K.L., J. Vanos, J.W. Baldwin, J.E. Bell, D.M. Hondula, N.A. Errett, K. Hayes, C.E. Reid, S. Saha, J. Spector, and P. Berry, 2021: Extreme weather and climate change: Population health and health system implications. *Annual Review of Public Health*, **42** (1), 293–315. https://doi.org/10.1146/annurev-publhealth-012420-105026

433. Dennison, P.E., S.C. Brewer, J.D. Arnold, and M.A. Moritz, 2014: Large wildfire trends in the western United States, 1984–2011. *Geophysical Research Letters*, **41** (8), 2928–2933. https://doi.org/10.1002/2014gl059576

434. Parks, S.A. and J.T. Abatzoglou, 2020: Warmer and drier fire seasons contribute to increases in area burned at high severity in western US forests from 1985 to 2017. *Geophysical Research Letters*, **47** (22), e2020GL089858. https://doi.org/10.1029/2020gl089858

435. Kitzberger, T., D.A. Falk, A.L. Westerling, and T.W. Swetnam, 2017: Direct and indirect climate controls predict heterogeneous early-mid 21st century wildfire burned area across western and boreal North America. PLoS ONE, **12** (12), e0188486. https://doi.org/10.1371/journal.pone.0188486

436. Hurteau, M. and M. North, 2008: Mixed-conifer understory response to climate change, nitrogen, and fire. *Global Change Biology*, **14** (7), 1543–1552. https://doi.org/10.1111/j.1365-2486.2008.01584.x

437. Hurteau, M.D., S. Liang, A.L. Westerling, and C. Wiedinmyer, 2019: Vegetation-fire feedback reduces projected area burned under climate change. *Scientific Reports*, **9** (1), 2838. https://doi.org/10.1038/s41598-019-39284-1

438. Littell, J.S., 2018: Drought and fire in the western USA: Is climate attribution enough? *Current Climate Change Reports*, **4** (4), 396–406. https://doi.org/10.1007/s40641-018-0109-y

439. Stowell, J.D., G. Geng, E. Saikawa, H.H. Chang, J. Fu, C.-E. Yang, Q. Zhu, Y. Liu, and M.J. Strickland, 2019: Associations of wildfire smoke $PM_{2.5}$ exposure with cardiorespiratory events in Colorado 2011–2014. *Environment International*, **133**, 105151. https://doi.org/10.1016/j.envint.2019.105151

440. Dixon, L., F. Tsang, and G. Fitts, 2018: The Impact of Changing Wildfire Risk on California's Residential Insurance Market. California's Fourth Climate Change Assessment. CCCA4-CNRA-2018-008. California Natural Resources Agency. https://www.energy.ca.gov/sites/default/files/2019-12/Forests_CCCA4-CNRA-2018-008_ada.pdf

441. Wang, D., D. Guan, S. Zhu, M.M. Kinnon, G. Geng, Q. Zhang, H. Zheng, T. Lei, S. Shao, P. Gong, and S.J. Davis, 2021: Economic footprint of California wildfires in 2018. *Nature Sustainability*, **4** (3), 252–260. https://doi.org/10.1038/s41893-020-00646-7