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Frank W. Davis and Elizabeth A. Chornesky

Abstract

Many aspects of the Californian approach to controlling the greenhouse gases that cause climate change now have a sufficient track record to provide potential models or lessons for national and even international action. In comparison, the state's efforts on climate change adaptation, although multifaceted, are less well developed and thus far have focused largely on information sharing, impact assessments, and planning. Still, adaptation could advance more quickly in California than in many other regions, given relatively high public awareness and concern, extensive scientific information, a strong tradition of local and regional planning, and some enabling policies and institutions. Much more political support and sufficient financing will have to be mustered at state and local levels to enable new projects and initiatives to cope with sea level rise, water management, and ecosystem adaptation, not to mention public health and other key areas of concern. Even so, California's initial efforts to adapt to unavoidable changes in climate may offer insights for other governments that will, inevitably, need to fashion their own adaptation strategies.

Keywords

climate adaptation, climate change, ecosystem services, endangered species, sea level, water supply

California is in the vanguard of states acting to mitigate and adapt to human-caused climate change, and for good reasons. Public health and safety and trillions of dollars of real assets are at increasing risk from rising sea level and more frequent heat waves, floods, and wildfires. Intensifying droughts, shrinking mountain snowpacks, and growing urban water demand are challenging the state's already overtapped water supply system. Changes in precipitation and hotter conditions pose multiple threats to the state's $43 billion agricultural sector. A hot spot of biodiversity, California leads all states in the number of threatened or endangered animal species and is second only to Hawaii in the number of endangered plant species, and pressures on those species are only likely to increase with climate change. Compounding these concerns is the inexorable growth in the state's human population, which is projected to rise from 38 million today to 60 million by 2050.

While it is hard to find any positives in climate change projections for the Golden State, there are encouraging signs that federal, state, and local

governments are getting serious about confronting the challenges. The state has completed three scientific climate assessments, most recently in 2012, and has provided a wealth of online data and information.[1] Assembly Bill 32 (the 2006 Global Warming Solutions Act), the centerpiece of California's climate change mitigation policy, has codified 2020 targets for reduced greenhouse gas emissions and enabled the associated cap-and-trade program instituted in 2011. The state drafted its first climate adaptation strategy in 2009 (hereafter, the 2009 strategy) highlighting approaches to reduce the harm and exploit possible benefits of unavoidable climate change (California Natural Resources Agency, 2009). A 2013 revision of the state's adaptation strategy (the 2013 revision) is presently being vetted by the governor's office and is available for public comment (California Natural Resources Agency, 2013).[2]

Clearly, Assembly Bill 32, in concert with other state and federal policies, is effecting significant changes in how California's energy, transportation, construction, agricultural, and natural resource sectors generate and mitigate greenhouse gas emissions. But these are early days in California's adaptation efforts, and it's not yet clear whether California will be able to make the kinds of transformational changes in policy and management strategies and tactics that many believe are required to contend with unavoidable impacts of climate change that will likely occur over the next several decades (Bierbaum et al., 2013).

It only takes a few minutes browsing the Internet to get a sense of the high level of attention to climate change adaptation across the state. These efforts are multifaceted and multi-jurisdictional, which should come as no surprise, given California's political geography. Roughly half of the state is federal lands, including more than 20 million acres of national forest lands, 14 million acres managed by the Bureau of Land Management, 7.4 million acres in national parks, and 4 million acres in military bases. The state is partitioned into 58 counties and includes nearly 500 cities and towns, 109 federally recognized tribes, and 100 Native American community areas, or rancherias. Like climate change itself, adaptation to climate change is manifest to different degrees, proceeding at different rates, and producing different responses in different locations and jurisdictions.

The 2009 strategy defines adaptation as "efforts that respond to the impacts of climate change—adjustments in natural or human systems to actual or expected climate changes to minimize harm or take advantage of beneficial opportunities." We see adaptation as a set of interrelated activities that include engaging and motivating stakeholders across sectors and social institutions; providing best available data, information, tools, and guidance to inform actions at multiple scales and jurisdictional levels; producing coherent strategies and priorities for adaptation actions; procuring new or redirecting existing funds to achieve meaningful adaptation; and implementing adaptation strategies through new infrastructure, policy, and management actions and reforms (including monitoring and evaluation).

Given the scope and diversity of adaptation responses in California, we will not attempt a comprehensive review of progress to date, but will try instead to offer a sense of the pace of adaptation progress at the state and local levels in three issue areas with which we are most

familiar: sea level rise, water management, and the conservation and management of wild species and ecosystems.

Many aspects of California's approach to controlling the greenhouse gases that cause climate change have developed a sufficient track record to provide potential models and lessons for national and even international action. In comparison, the state's efforts on climate change adaptation are less well developed and thus far have focused largely on information sharing, impact assessments, and planning. Even so, these beginning efforts may offer insights for other governments that are fashioning, or will, inevitably, need to fashion, their own adaptation strategies to address the unavoidable changes ahead.

The unavoidably rising seas

Unlike many other consequences of climate change, sea level rise, while gradual, is comparatively certain and will continue for centuries if not millennia (Levermann et al., 2013). The direct impacts are tangible; they are confined to narrow but disproportionately important coastal regions that in California encompass three-quarters of the state's population. And the technical know-how exists to adapt to sea level rise. This may explain why adaptation efforts to address sea level rise are more apparent and perhaps better developed than those related to other climate change impacts.

Sea level rise in California is complicated by crustal plate dynamics that are gradually raising the elevation of coastal areas north of Cape Mendocino and causing coastal areas to subside south of the Cape (NRC, 2012). The expected result is that sea level will rise unevenly, with faster and greater changes occurring south of Cape Mendocino in comparison to the more sparsely settled northern coast. Southern California sea level rise projections from the National Research Council (2012) range from 12 to 61 centimeters (4.7 to 24 inches) by 2050 and 42 to 167 centimeters (16.5 to 65.7 inches) by 2100, representing a four- to eightfold increase over the rate of sea level rise in the 20th century. In addition to the range in these estimates, there are other uncertainties that bear on projecting the local impacts of sea level rise, including local shoreline conditions, surface winds and associated wave heights, and the magnitude and timing of storm surges and flow levels in coastal streams and rivers. Despite these uncertainties, higher seas will doubtless be accompanied by increased coastal flooding, coastal erosion, loss of coastal wetlands and beaches, and saltwater intrusion into coastal aquifers and rivers. Saltwater intrusion into the Sacramento-San Joaquin Delta is especially worrisome because of the delta's key role in water conveyance from northern to southern California (Hanak and Lund, 2012).

For sea level adaptation, California's 2009 strategy emphasized avoiding additional development in future hazard zones, redesign of coastal structures where feasible, initiation of state and local planning to address impacts, and continuing data and information gathering and vulnerability assessment. The 2013 update presents more recent information on potential impacts to coastal environments, transportation infrastructure, water supply, and other development. The update also highlights the issue of toxic material releases from flooded coastal facilities such as underground storage tanks, Superfund sites, and closed landfills.

Since 2009, most adaptation efforts in California have focused on vulnerability assessment and early-stage planning. A California Sea-level Rise Guidance Document, adopted by the California Ocean Protection Council in 2011 and last updated in 2013, offers advice on how state agencies can incorporate sea level rise projections into planning and decision making and provides a mechanism for rapidly integrating advances in scientific understanding into the actions of diverse state agencies implemented under varying authorities. Many state agencies have adopted it, although not all of the 50 or so agencies that deal in one way or another with coastal climate change impacts.

California's approach to climate change adaptation and sea level rise includes attempts to engage and motivate stakeholders. For example, to help citizens visualize future risks, the California King Tides project (http://california.kingtides.net/), established in 2010, disseminates photos of the highest tides occurring today, which are akin to the projected average daily high tides in 2050. The state has also supported acquisition of a large amount of information now available on the Internet, including high-resolution shoreline mapping data acquired via LIDAR, or light detection and ranging, a technology that uses pulsed lasers to measure ranges of distances to the Earth (www.opc.ca.gov/2012/03/coastal-mapping-lidar-data-available/).

Grant programs administered by state entities, including the California Ocean Protection Council and the state Coastal Commission, have supported roughly 50 planning efforts by local governments. The Center for Ocean Solutions' website for Monterey Bay (www.centerforoceansolutions.org/monterey-bay/) illustrates the kinds of local resources that are becoming available to support strategic planning to deal with rising seas. The City of Malibu's Local Coastal Program (http://qcode.us/codes/malibu-coastal/) now requires consideration of projected sea level rise in any applications for new shoreline protective structures or coastal development. And a host of stakeholders—including local governments, the Port of San Diego, and the San Diego Airport Authority—have collaborated to create a Sea Level Rise Adaptation Strategy for San Diego Bay (www.icleiusa.org/climate_and_energy/Climate_Adaptation_Guidance/san-diego-bay-sea-level-rise-adaptation-strategy-1).

Overall, sea level adaptation efforts in California have been more focused on understanding local and regional vulnerabilities, as opposed to the more complex evaluation of social and economic tradeoffs associated with alternative adaptation strategies. Eventually, however, government agencies will have to take the potentially contentious steps of identifying which actions to take and where to take them. As the waters rise, public trust responsibilities—for water quality, ecosystem services, endangered species, public access, and recreation—will almost inevitably come up against private property rights, potentially raising takings issues. For example, as sea level rise shifts the boundary between public intertidal water and adjacent coastal private properties, newly tidal areas would in principle come under public ownership though the "doctrine of accretion" (Byrne, 2012). Public efforts taken in advance of sea level rise—such as modifying Local Coastal Programs to further restrict allowable land uses in vulnerable

areas—could reduce property values and be challenged as a regulatory taking. Landowners applying to construct seawalls and taking other measures to reduce property loss could be opposed, on the grounds that they are effectively denying the public new intertidal areas. Herzog and Hecht (2013) review these and a number of other potential public–private conflicts brought about by sea level rise, emphasizing that California has considerable authority and regulatory power to address these conflicts and advance adaptation in coastal areas.

Sea level adaptation efforts are under way in many coastal states and local areas around the United States, and the situation in California is similar to other vulnerable regions where adaptation planning is proceeding, especially at the local level, but implementation is somewhat piecemeal and moving more slowly (Gregg et al., 2011). California has a leg up over some regions, with its strong state policies—such as the Coastal Act and California Environmental Quality Act—that give local governments the legal authorities needed to consider sea level rise in local planning, regulation, and development permitting. State and regional institutions like the California Coastal Commission, the Coastal Conservancy, the Ocean Protection Council, and the San Francisco Bay Conservation and Development Commission can fund and coordinate planning efforts to hasten implementation progress (Hanak and Moreno, 2012; Herzog and Hecht, 2013).

Managing water supply and flood risks

Climate models for California project warming of 2.3 to 3.6 degrees Celsius over the next 50 years, three to six times the 20th-century warming rate, with the largest increases coming during summer months and in areas further from the coast (Pierce et al., 2013). Projected warming could reduce late winter snowpack in the Sierra Nevada and Mount Shasta regions by 25 to 40 percent by mid-century and substantially increase evaporation rates and crop water use (Hanak and Lund, 2012). Most climate models now project a slight increase in precipitation in the northern two-thirds of the state, especially in winter precipitation, and little change or decreased precipitation in the southern third of the state (Neelin et al., 2013; Pierce et al., 2013), amplifying existing regional disparities. Rainfall extremes and associated flood risk are expected to increase (Das et al., 2013), as are year-to-year rainfall variability and the risk of intense droughts (Gershunov et al., 2013).

If they happen, these changes in California's hydrologic cycle will pose myriad challenges to state water managers. The mountain snowpack provides needed seasonal water storage and, historically, has effectively increased the state's reservoir capacity by 35 percent, supported hydropower generation from mountain reservoirs, and helped maintain reliable flows and cooler stream temperatures during summer months. If more winter precipitation falls as rain, and storm intensity increases, peak river flows are more likely to exceed the capacity of current flood control structures such reservoirs, levees, and bypasses (Das et al., 2013; Hanak and Lund, 2012). Sea level rise will compound water-supply and flood-management problems as salinity lowers water quality in surface and groundwater supplies and increases the likelihood of levee

failure in the Sacramento-San Joaquin Delta region.

California's 2009 adaptation strategy calls on state agencies to reduce per capita water use by 20 percent by 2020, expand water storage, take steps to harmonize water supply, quality, and ecosystem conditions in the Sacramento-San Joaquin Delta, support agricultural water use efficiency, and improve statewide water quality. Since then, the state has taken a variety of adaptation steps in regard to water use, including the Water Conservation Act of 2009 which mandates a 20 percent reduction in per capita water use, a recycled-water policy aimed at local water supplies, planning efforts for improved management of the Sacramento-San Joaquin Delta, and expanded technical support related to climate change for Integrated Regional Water Management planning groups. State agencies have also produced a variety of new guidance documents for local communities related to flood risk management.

As Public Policy Institute of California researcher Ellen Hanak and University of California, Davis, watershed management expert Jay R. Lund (2012) point out, California is no stranger to water-management challenges, and considerable infrastructure, institutional capacity, and experience are in place to confront climate change. Water demand can be influenced, for example, through pricing, taxes, and gains in efficiency. Similarly, there are many water-supply management and expansion options, such as improved groundwater management and water reuse. In one sense, then, the water-management arena in California is already well equipped to adapt to climate change. There is a high level of awareness of the issues, a large amount of data, considerable analysis of options and priorities, and an institutional capacity to act.

On the other hand, it is not at all clear that political leaders will take the necessary actions to confront climate change impacts, or that agricultural, urban, and other interests will accept and pay for them. Adaptation will require better tracking of groundwater use, agricultural water-management practices, and surface water diversions, as well as better enforcement of current water use policies (Hanneman et al., 2012). Funding for operational reforms and new infrastructure is a pervasive issue, and passage of an $11.4 billion water bond that is on the 2014 ballot is far from assured.

California is not the only state dealing with climate change and water supply. The western United States has experienced multiple severe droughts over the past 12 years that have driven home the magnitude of the threat posed by climate change and the need for coordinated adaptation responses, especially among the seven southwestern states that are signatory to the Colorado River Compact (Sabo et al., 2010). Climate change is being incorporated into water-management planning by most states and major municipalities, with increasing information sharing and coordinated planning, as illustrated by the Water Utility Climate Alliance (www.wucaonline.org/). But water policy experts in the western United States are quick to point out that needed policy and management reforms are slow in coming and fall considerably short of what will be needed to cope with combined climate change and population growth (Gleick, 2010; Sabo et al., 2010).

Climate adaptation and ecosystem resilience

California's diverse species and ecosystems are already undergoing climate-driven changes, including uphill shifts in distributions of plant and animal species and more frequent wildfires. The past 15 years have seen unprecedented rates of drought-related forest tree mortality across a wide range of elevations in the Sierra Nevada. Such changes will likely grow more pervasive, pronounced, and ecologically disruptive over the next several decades, as species' habitats become climatically less suitable and further stressed by changes in wildfire frequency, land use, and wide-ranging nonnative pest species. Coastal wetlands will be inexorably pinched between rising seas and coastal development. Conifer systems and grasslands could decline significantly, while other ecosystems, such as shrublands, desert scrub, and oak woodlands, could expand (Shaw et al., 2011). These changes will probably increase the number of threatened plant and animal species (Loarie et al., 2008; Moritz et al., 2008). Ecosystem services such as carbon sequestration and rangeland forage for livestock and wildlife species could be significantly impacted (Shaw et al., 2011).

Ecosystem adaptation—shorthand for strategies that support the functioning of and delivery of societal benefits from current and future ecosystems—is very much a work in progress, not only in California but globally (Chornesky et al., in review; Hobbs et al., 2013). California's 2009 adaptation strategy approach to ecosystem adaptation lacked tractability or integration across sectors. The generality of the strategy's primary recommendations—for the state to develop plans for an expanded network of protected habitat reserves and to improve management practices—perhaps reflects our limited ability to predict how species and ecosystems will respond to climate change and the context specificity of those responses. Moreover, while a relatively large scientific literature exists on the ecological consequences of climate change in California, that literature tends to be highly technical, lacks site-specificity, and has not been fully translated into guidance that is accessible to and usable by natural-resource managers. As a result, many ecosystem conservation and management plans now acknowledge the threat of climate change, especially on public lands and lands managed by conservation organizations. But far fewer specify adaptation strategies or priorities, much less specific actions.

There are, of course, exceptions. Ecosystem adaptation has become an increasing focus for coastal and floodplain ecosystems, often integrated with adaptation responses for public health and safety. For example, in southern California the Ventura Coastal Resilience project provides online resources to help resource managers and planners evaluate ecological as well as socioeconomic vulnerabilities to climate change (http://coastalresilience.org/geographies/ventura-county). For more than a decade, the Nature Conservancy has systematically prioritized and begun to acquire and restore floodplain properties along the Santa Clara River in Ventura County, benefitting native riparian species, reducing flood risks, and increasing resilience to sea level rise. This project is further along than most,

but many others are at least reevaluating ecosystem management goals and objectives in the face of sea level rise.

For example, UC Davis watershed expert Peter B. Moyle and his co-authors (2014) provide four strikingly different future scenarios for the San Francisco Bay Delta's Suisan Marsh, the largest tidal wetland on the West Coast, which is threatened by both land subsidence and sea-level rise. Suisun Marsh has been closely managed in recent decades by 158 private duck clubs and the California Department of Fish and Wildlife to maintain freshwater marshes for waterfowl hunting. These nontidal wetlands, many now lying below sea level, are maintained by an elaborate system of dikes, pumps, drains, and tidal gates to exclude brackish tidal water. Sea level rise and soil subsidence resulting from annual pond draining are requiring increasingly expensive water management. By mid-century, maintaining the current system could be prohibitively costly and might eventually fail. Alternative management regimes that allow more of the marsh to transition to tidal regimes are conceivable but would require buy-in from disparate stakeholders—from governments to environmental groups to business interests.

Federal land management agencies have also begun to take initial steps toward ecosystem adaptation measures. Since 2011, the Forest Service has required each national forest and ranger district to complete a Climate Change Performance Scorecard that asks, among other things, to what extent the unit has assessed climate change vulnerabilities of communities and ecosystems, taken action to reduce those vulnerabilities, and monitored the effectiveness of that action. Several national forests in California (e.g., the Tahoe National Forest, Sierra National Forest, and Inyo National Forest) are early adopters of new guidance that emphasizes managing for forest diversity and resilience, as opposed to fixed targets for forest composition and structure (Littell et al., 2012). In 2010, the US Fish and Wildlife Service initiated the California Landscape Conservation Cooperative, one of 22 such organizations established nationwide. Operated as a partnership among various private organizations and federal and state agencies, the cooperative has since been supporting place-based planning and, recently, pilot projects through the development and sharing of scientific knowledge and tools (http://californialcc.org/).

On private lands, the combination of climate change and urban and suburban development to accommodate California's rapidly growing population could put some regions on a crash course with federal and state endangered species laws. For the past 20 years, most of the largest potential conflicts between development and endangered species legislation have been addressed through the California Natural Community Conservation Planning (NCCP) Act, passed in 1991 and revised in 2003, which provides a mechanism for permitting development under the federal and state endangered species acts (Greer, 2004; Pollak, 2001). The program develops large, multi-species habitat preserves through cooperative agreements among federal and state agencies, county and city governments, environmental and homebuilder groups, and others. The process now plays a significant role in where and how endangered species conservation occurs in the state. Eight

NCCP areas are already being implemented over 3.4 million acres of land, and another 18, encompassing some 31 million acres of public and private lands, are in planning stages.

Until recently, the conservation strategies in such agreements have paid only lip service to the possible impacts of climate change on mitigation plans and the long-term viability of fixed species reserves. That could be changing. The largest NCCP agreement ever attempted in California is currently being produced for the California Mojave and Sonoran Deserts; it would reconcile California's dual policy goals of large-scale renewable energy development and conservation of desert plants and animals. The Desert Renewable Energy Conservation Plan was initiated in 2008 by the California Energy Commission, the California Department of Fish and Wildlife, the US Bureau of Land Management (BLM), and the US Fish and Wildlife Service (www.drecp.org/). If approved, this conservation plan would serve as a Multi-Species Habitat Conservation Plan under the US Endangered Species Act, a Natural Community Conservation Plan under the California Natural Community Conservation Plan Act, and a land-use plan amendment in the seven affected counties (Chornesky et al., in review). In contrast to earlier plans, this planning effort included a BLM-commissioned analysis of regional habitat connectivity under both current and future climatic conditions (Penrod et al., 2012) that would create a set of 22 linkage areas thought to be important for allowing species to shift their distributions in response to climate-driven habitat changes. The fate of this linkage plan is uncertain but, if adopted, this design would be the most geographically extensive and practical attempt thus far to use the conservation of corridors as a climate adaptation strategy.

California has undertaken other noteworthy efforts to build climate change into conservation strategies, including the state's Essential Habitat Connectivity Project (www.dfg.ca.gov/habcon/connectivity/). Climate change adaptation will figure prominently in the update to the California Wildlife Action Plan (www.dfg.ca.gov/swap/), slated for completion in 2015, which also will incorporate elements of the Essential Habitat Connectivity Project. The new strategic plan of the California Wildlife Conservation Board, which supports wildlife conservation through grants for land acquisition, easements, habitat restoration, and public access ($62 million in 2013), identifies addressing the impacts of climate change on biodiversity and ecosystems as a priority (www. wcb.ca.gov/).

Finally, there is a bit of progress in funding adaptation activities on the ground. The California Legislature recently approved the flow of $42 million from the latest cap-and-trade auction of pollution allowances to the Department of Forestry and Fire Protection for a variety of forest management projects that could improve forest resilience to climate change, as well as $25 million to the Department of Fish and Wildlife for watershed and wetland restoration that could benefit ecosystem adaptation efforts.

California's extreme ecological diversity, combined with relatively progressive policies with respect to conservation planning and biodiversity protection, makes it an important case study in ecosystem adaptation under climate change. Regional planning processes, enabled through multi-county associations of governments, regional

transportation and air quality planning efforts, and NCCP processes provide an opportunity for integrated regional planning to accommodate both development and biodiversity protection. Although cumbersome, such processes create an important opportunity for climate adaptation planning for multiple species and ecosystems across large multi-jurisdictional areas.

The future of adaptation

Unlike climate mitigation, climate adaptation in California lacks a strong state legal mandate that incentivizes and funds implementation of adaptation strategies. At the moment, therefore, adaptation is more talk and analysis than action. But talk is important; land-use, natural resource, and water-management planning processes are increasingly conducted through a climate change lens as government officials prepare strategies that will eventually influence funding priorities and decision making at local, regional, and statewide levels.

Also, in California ample evidence exists of growing stakeholder motivation and engagement in regard to adaptation efforts. The state has done a good job developing data and information resources through programs such as the Climate Change Research Center (www.energy.ca.gov/research/environmental/climate.html)—the first state-funded climate change research program in the nation—which between 2003 and 2013 funded some 415 projects in areas that include climate modeling and monitoring, greenhouse gas inventory, mitigation options, and adaptation. Results from these and other research efforts are readily discoverable via the Cal-Adapt website (http://cal-adapt.org/).

Strategies and priorities for climate change adaptation are beginning to emerge at many scales and jurisdictional levels in California. Adaptation is further along and could advance more quickly in California than in many other regions, given relatively high public awareness and concern, extensive scientific information, a strong tradition of local and regional planning, and some enabling policies and institutions. Much more political support and sufficient financing will have to be mustered at state and local levels to enable new projects and initiatives to cope with sea level rise, water management, and ecosystem adaptation, not to mention public health and other key areas of concern. A broad stakeholder base must still be built. Along those lines, in August 2014, the state government will partner with the Local Government Commission to hold a two-day California Adaptation Forum (www.californiaadaptationforum.org/), the first of what is intended to be regular biennial events aimed at promoting local networking and engaging stakeholders in advancing climate adaptation solutions.

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Note

1. See www.climatechange.ca.gov.
2. The revised adaptation strategy was published July 31, 2014, at the time this article was in final preparation.

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Elizabeth A. Chornesky is an independent consultant whose practice focuses on assisting California philanthropies, public agencies, and nonprofit organizations in developing science, policy, and investment strategies related to ecosystem management and global change. She previously directed the national stewardship and applied research programs of the Nature Conservancy and served as a project director and policy analyst at the US Congress Office of Technology Assessment. Her early career was as a research scientist in marine ecology at the Smithsonian Institution and Lehigh University, USA. She earned her BA from Cornell University in 1978 and PhD in biology from the University of Texas at Austin in 1984.