Climatic Change (2012) 111:135–163
DOI 10.1007/s10584-011-0246-y

Conservation and management of ecological systems in a changing California

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Received: 13 August 2009 / Accepted: 5 July 2011 / Published online: 15 October 2011

Abstract Climate change in California is altering habitat conditions for many species and exacerbating stress from other factors such as alien invasive species, pollution, and habitat fragmentation. However, the current legal and planning framework for species protection does not explicitly take climate change into account. The regulatory framework is primarily reactive, kicking in only after species' health is gravely threatened. Neither federal nor state regulations require forward-looking, climate-sensitive species or ecosystem protection plans. Habitat planning is poorly funded and often piecemeal. In this context, the wrong lands may be protected, with development allowed to occur in areas that would be most beneficial for species conservation in the future. A more forward-looking approach to habitat conservation is needed, one based on a statewide strategy to identify and protect critical habitat areas, including corridors to enable species migration. The approach would also require development of assessment indicators and assistance strategies not dependent on current habitat structure, and a governance structure to implement regular, periodic updates of management plans in relation to agreed-upon performance indicators. Such a strategy should integrate habitat conservation planning with other state and regional plans and objectives, such as for transportation infrastructure, urban development, and mitigation of climate change.

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1 Introduction

California represents a microcosm of the complex issues related to conservation and climate change, with a large economy that benefits from diverse ecosystem services (Kremen et al. 2002), species already experiencing pressures from both development and climate change (McLaughlin et al. 2002), and a web of legal structures and societal activity related to conservation. California has been a laboratory for testing innovative environmental policies, such as the forward-looking, regional approach to habitat conservation encouraged by the Natural Communities Conservation Planning Act. Yet, in spite of existing policies and investments, the state's governance framework for habitat conservation remains unprepared to adequately address effects of climate change.

Protecting California's diverse species and ecosystems is a daunting task even in the absence of human-induced climate change. California is considered one of the world's biodiversity "hotspots," reflecting its numerous endemic species, as well as the large impacts from economic development that have occurred over the past 150 years (Myers et al. 2000). Climate change introduces additional, uncertain impacts to California's ecosystems and species, ranging from changes in the timing of bird migrations in spring, to large-scale redistribution of species on the landscape, to increases in forest fires. Such impacts threaten to pull apart current natural communities, and will push many species toward extinction. In addition, climate change will interact with other stressors, such as habitat destruction, that are already threatening species and ecosystems, making it more difficult to achieve conservation goals.

The laws and policies already in place to promote conservation efforts embody the state's commitment to other species: that cultural and economic achievements will not come at the expense of species' very survival. California has been a national leader in promoting proactive, bioregional conservation strategies to avoid conflicts between environmental and economic goals. However, human-induced climate change now undermines the commitment to species preservation enshrined in those laws and programs. Under a changing climate, traditional conservation strategies, such as habitat protection in fixed reserves, may not be adequate for protecting species and ecosystems. The current policy structure for conserving species must be adapted to this widely recognized threat or the state will, in effect, be abdicating its original commitment.

In fundamental ways, the current challenge in conservation policy is a governance challenge. The state needs to define more precisely its goals and priorities for conservation policy, and establish a governance structure that is flexible and responsive across space and over time. That governance structure should integrate conservation planning across regions with other planning processes, and provide for systematic, ongoing adaptive management of species and ecosystems in relation to clear performance indicators. To accomplish these goals, the state also needs to secure a more stable, ongoing source of funds for these purposes.

Even as climate change presents a challenge for efforts to manage and protect California's rich natural heritage, it also presents certain opportunities. In some cases, the adaptation strategies needed to help ecological systems cope with upcoming changes may produce co-benefits by helping reduce greenhouse gas emissions and by promoting economic efficiency. However, to realize the potential of such win-win approaches, a stronger state commitment is needed to coordinate climate mitigation with adaptation, and to coordinate resource management and urban development with ecosystem conservation and restoration.

In the rest of this article, we describe more fully the conservation and resource management challenges in California for protecting biodiversity in the face of climate change, focusing on conservation of natural land-based habitat. We first highlight the conservation challenge and the risks to species and ecosystems posed by climate change. We then review the primary laws and regulatory processes currently used to prevent species extinction and conserve habitat. Next, we discuss challenges and opportunities for adapting the current policy structure to the realities of climate change, and consider how laws and programs to aid species and ecosystem conservation might be modified to be more adaptive.

2 Current threats to native species and ecosystems

Protecting California's species and ecosystems is a daunting task even in the absence of human-induced climate change. Due to its size, dramatic topography, varied geology and soils, and diverse climates, California has more species and ecosystems than any comparably sized US region, with more than 6,500 native species, almost 1,300 of which are endemic, or found nowhere else on earth (Stein 2002; Stein et al. 2000). California's biodiversity is threatened by compound stresses including habitat loss, deterioration, and fragmentation from economic activities (dams and water diversions, urban growth, agricultural expansion, and forestry), as well as pressures from invasive species. These combined threats have already put more than 30% of the state's flora (nearly 1,700 species) and over 15% of California's vertebrate wildlife (125 species) at risk of extinction (Stein 2002; Stein et al. 2000). Yet less than one-fifth of California land is in public reserves managed for biodiversity values, nearly all of it in mountainous or desert regions. About 64% of land is public and private "working landscape," such as rangelands or forests managed for timber, which provide both habitat for native species and economic returns (Office of Environmental Health Hazard Assessment 2004). The state's remaining land, dedicated to agricultural and urban uses, is significantly transformed by human activity.

California's wetland and aquatic ecosystems have been particularly diminished by urban development and agriculture. California has lost over 90% of its original wetlands acreage—more than any other state (California Continuing Resources Investment Strategy Project 2001). Two hotspot regions in particular—the San Francisco Bay-Delta and southern coastal California—have lost substantial natural habitat due to urban and agricultural development. In the Delta, California's highly engineered water system has dramatically altered the volume, seasonality, and quality of water flows. Dams and diversions create barriers to fish migration and spawning, resulting in spring-run Chinook salmon populations just 1% of their historic size and with only 20% of their historic spawning habitat accessible (Bunn et al. 2007). Several other Bay-Delta dependent species also are listed on the federal and state threatened and endangered species lists.

In southern coastal California, the remaining habitat is significantly fragmented, with populations of endemic or rare species increasingly isolated from one another. Urban development has consumed 40% of the land area, reducing vernal pool habitat by 95% and coastal sage scrub by 82% (Bunn et al. 2007). These habitats harbor rare plants and animals adapted to the Mediterranean climate (i.e., cool, wet winters and hot, dry summers) and seasonal wetlands.

Other ecosystems in the state have experienced significant disruption from invasive species and past timber harvest or grazing (Bunn et al. 2007). Current old growth forest is about one quarter of its historic extent (Fire and Resource Assessment Program 2003). During the 1990s and early 2000s, forestland in the state was converted to other uses at an average annual rate of more than 15,000 acres per year (Climate Action Team Economic Subgroup 2007). Similar conversion rates are expected to continue to 2020.

3 Risks from climate change

Climate change introduces additional, uncertain risks to California's ecosystems and species ranging from changes in the timing of biological events such as bird migrations, to large-scale redistribution of species on the landscape, to increases in forest fires. Some of these changes are documented and underway, while others are projected based on some understanding of species and ecological communities combined with scenarios of future climate. Most notable, perhaps, is the expectation that future changes in temperature and precipitation will place many plant and animal species at risk of extinction (20 to 30% of those assessed so far) if global temperatures exceed 2.7 to 4.5°F (1.5 to 2.5°C) above the historic average (IPCC 2007). In turn, this threat will be compounded by other ongoing challenges to species survival.

Climate change is already underway in California (Barnett et al. 2008; Bonfils et al. 2007). Recent studies have documented ecological changes coincident with observed climate changes for a number of species and ecosystems. For example, the community of organisms living along California's rocky coastline now includes more southerly species than it did several decades ago (Sagarin et al. 1999), many small mammal species in Yosemite National Park have shifted their ranges upward in elevation over the last century (Moritz et al. 2008), and migrant songbirds are arriving earlier along with earlier spring weather (Cayan et al. 2001; Macmynowski et al. 2007). In addition, pine and fir trees in old-growth Sierra Nevada forests are dying more readily, thanks to longer drier summers (van Mantgem and Stephenson 2007) and high-elevation forests are more vulnerable to wildfire with earlier spring snowmelt (Westerling et al. 2006).

Climate-induced risks, including large-scale changes in species distribution and increases in extinctions, challenge the notion that habitat protection in static preserves distant from one another will ensure the future of many species, particularly endemic ones. For species occupying a limited area, the loss of climatically suitable habitat in an existing reserve could result in significantly smaller populations. Climate change may alter the ecological communities protected by any single reserve. For example, reserve areas currently containing blue oak, such as Henry Coe State Park, may not be suitable for this species in future decades due to climate change (Kueppers et al. 2005; Fig. 1). Other reserves, such as Trinity Alps Wilderness, may be newly suited to blue oak but not to current species (Fig. 1).

Since endemic species do not occur outside of California, changes in their number and distributions are of particular concern. One study projected climate change-driven loss of habitat for endemic species in California at 16 to 64%, with anywhere from 2% to 46% of endemics facing extinction (Malcolm et al. 2006). Endemic species' geographic ranges are projected to shift northward and toward the coast (Loarie et al. 2008). Some regions, such as the Sierra Nevada foothills, may be highly vulnerable to declines in the number of endemic species, while other regions such as northwestern California, may be somewhat buffered from biodiversity losses (Loarie et al. 2008).

Anticipated ecological changes are contingent on the greenhouse gas emissions pathway the global economy adopts as well as on how well species can adjust to rapid change (Hayhoe et al. 2004; Loarie et al. 2008). The extent of species shifts and the magnitude of species losses are projected to be greatest under scenarios in which emissions are high, and species are constrained in their ability to migrate to new habitat (Loarie et al. 2008). Constraints to species movement could be biological (for instance, some species require host plants that are not as rapidly mobile (Pelini et al. 2009), or could be due to barriers such as mountain ranges or large expanses of inhospitable urban and agricultural land.

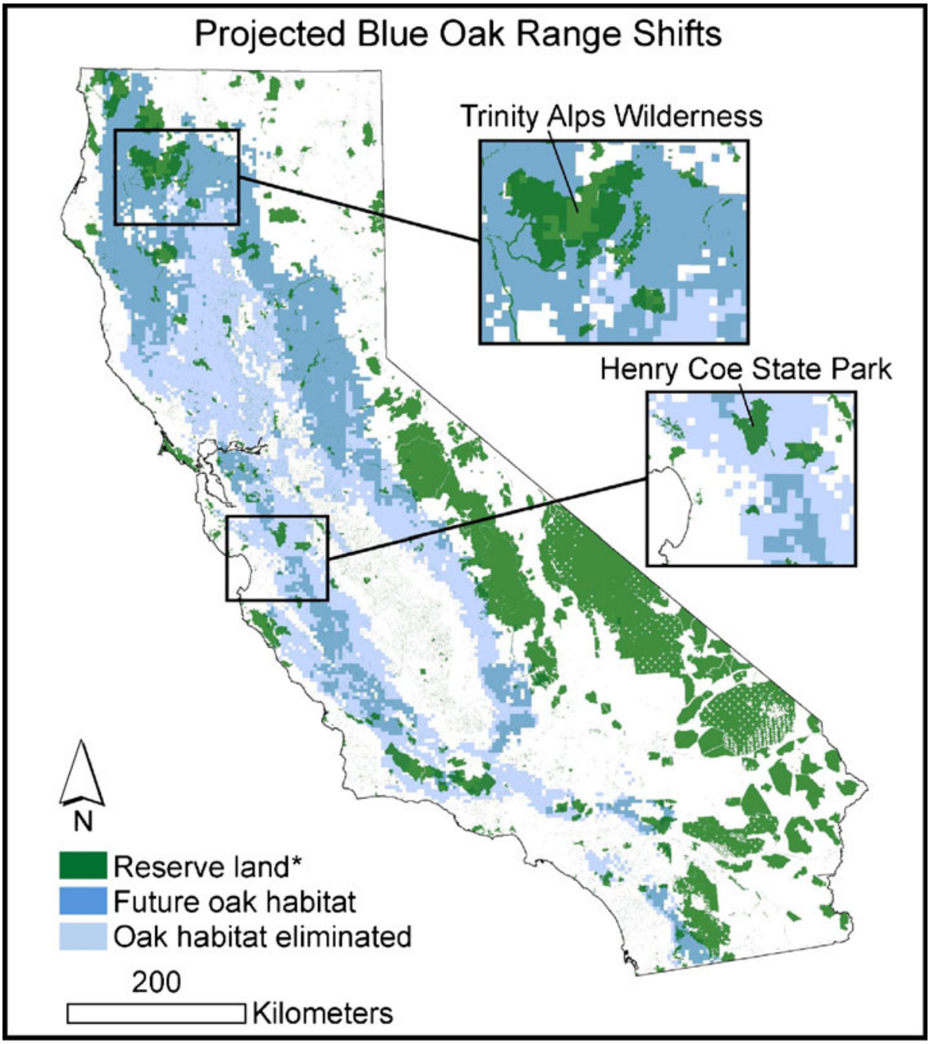

Fig. 1 Projected Blue Oak range shifts in California. Source for oak habitat: Kueppers et al., 2005. Source for land management status: California Department of Forestry and Fire Services: Fire and Resource Assessment Program. *Reserve lands include national and state parks, wilderness areas, private reserves and other areas where conservation is a primary objective

Currently, little is known about the ability of species to disperse to new habitats, let alone how quickly they might respond.

As the relative proportions of species in a given site changes, and as species shift their ranges (if they can), current ecological communities will be disaggregated and new communities with no modern analog may be formed. Such disaggregation may already be underway, as species with strongly synchronized timing for biological events, such as flowering time and arrival of pollinators, are now responding independently to recent warming in systems elsewhere (Visser and Holleman 2001). Little is known about species' ability to adjust behaviorally or physiologically as their current habitat changes. The projected changes for both climate and ecological systems are rapid and large compared to historical records, and will challenge the capacity of species to migrate and evolve (Davis and Shaw 2001). These factors make it difficult to predict how and on what time scales ecological communities will change.

Pre-existing threats such as habitat fragmentation and modified hydrologic patterns and “disturbance regimes” (flood, fire, disease or wind-induced changes) make species and ecosystems more vulnerable to climate change. For example, populations of the Bay checkerspot butterfly and desert bighorn sheep appear to be sensitive to variability in climate combined with significant habitat loss (for the butterfly) and interactions with domestic sheep (for the bighorn) (Epps et al. 2004; McLaughlin et al. 2002). The increased isolation of habitat patches decreases the likelihood that areas with local extinctions will be recolonized. Similarly, projected higher water temperatures will exacerbate the pre-existing effects of water exports on habitat volume and fish entrainment. This may undermine efforts to restore habitat for the endangered delta smelt to save this species from extinction (Bennett 2005; van Rheenen et al. 2004).[1]

Invasive species present a unique threat. Second only to habitat degradation and loss as a threat to native species, non-native invasive species eat or compete with natives, and/or have traits that help them flourish in disturbed environments (Wilcove et al. 2000). Recent work in grasslands suggests that invasive species are more successful when ecosystems have lost important native species (Zavaleta and Hulvey 2004). In some cases, invaders also may be favored by climate warming and increases in atmospheric CO_2, due partly to a more responsive dispersal ability (Dukes and Mooney 1999; Stachowicz et al. 2002). At the same time, climate change may make some areas less suitable for current invasive species, providing a unique opportunity for restoration (Bradley and Wilcove 2009). As new types of natural communities are formed, species now considered native in one locale may even become invasive in another if they present threats to existing natural assemblages.

In sum, species and ecosystems will respond to the direct and indirect effects of climate change in diverse ways. Current conservation practice may need to be redirected in the face of uncertain climate risks, raising the critical question of whether California’s current framework for conservation and resource stewardship is prepared for the challenge.

4 The regulatory framework for conservation and resource management

In California, as elsewhere, species are threatened most by economic activity, especially land development. And as in much of the rest of the world, California’s habitat conservation and management strategies must be integrated with economic activity. This integration relies on the efforts of a multitude of federal and state agencies that share responsibility for land, water and coastal resource management. The missions of many of these agencies incorporate recreational and economic production goals as key objectives along with conservation of ecological values such as biodiversity and ecosystem functions.

In response to conflicts that have emerged between urban development and habitat preservation, California has developed innovative programs to integrate economic development and conservation. These programs will aid the state in addressing planning challenges related to climate change. However, in fundamental ways, the existing planning and

[1] Spawning by the delta smelt occurs within a limited temperature range, with larvae intolerant of water above 20°C. Lower recruitment tends to occur in warmer years, because the number of days suitable for spawning is reduced.

regulatory system for protecting biodiversity remains ill equipped for meeting the challenge. In particular, the basic regulatory tools for protecting species are often implemented in a reactive and piecemeal fashion, and coordination is lacking across government jurisdictions and policy domains (for instance, water quality and forest management).

4.1 Species protection laws and programs

Within the larger framework of natural resource regulation, the primary laws for protecting species health on public and private lands are the federal Endangered Species Act (ESA), and its state equivalent, the California Endangered Species Act (CESA). ESA and CESA are considered tough environmental laws because of their stiff prohibitions against "take" of endangered plants and wildlife. "Take" means not just outright killing of listed organisms but also degradation of proximal habitat resulting in death or injury.[2]

The US Fish and Wildlife Service (FWS) and the California Department of Fish and Game (DFG) are responsible for designating species as endangered or threatened and for identifying critical habitat and developing recovery plans for those species. The agencies may issue permits to landowners whose actions result in take, if the permittees mitigate their action by setting aside land or otherwise providing compensation. For any federal agency action (including issuance of a permit) that could potentially affect listed species, the FWS must consider "the best scientific and commercial data" to determine whether the species would be placed at further risk by the action, and it may recommend actions to minimize impacts. The CESA also calls on DFG to base species listings and take permits on "the best scientific information available." However, while the ESA explicitly requires all federal agencies to consult FWS regarding actions that could affect listed species, the CESA does not currently contain a similar mandate.[3]

During the 1990s, the FWS and DFG developed programs to address shortcomings in the ESA and CESA resulting from piecemeal and reactive implementation. Landowners had grown frustrated by the cost and inconvenience of permitting (Pollak 2001a, b). In response, the FWS promoted multi-year permits, called habitat conservation plans (HCPs), coupled with a policy called "no surprises." Under this policy, if landowners set aside land or otherwise mitigate for take under an approved HCP, no further conservation actions are required from them beyond those stipulated in the plan for foreseeable, so-called "changed," circumstances. HCPs have become the primary mechanism for enforcing the ESA on private land (Opperman and Bernazzani 2003).[4]

Meanwhile, environmentalists had grown frustrated with the inadequacy of ESA's and CESA's regulatory approach—preserving small, unconnected parcels of land for one species at a time, and only after it was in trouble (Pollak 2001a, b). A strategy to provide

[2] The definition of "take" differs in CESA and ESA. ESA regulations define take to include "harm," which refers among other things to "significant habitat modification or degradation" that results in death or injury to wildlife. The CESA definition of take includes no such explicit reference to habitat modification, and in general, the California definition of take includes only acts that cause the death of a protected species. The Department of Fish and Game has applied CESA in such a way that habitat removal is prohibited if it is the proximate cause of death. However, in some cases, habitat modification may be considered take under the federal ESA, but not under the California ESA (Cylinder et al. 2004; Manthripragada 2006).

[3] Although not explicitly required by CESA, inter-agency consultation for actions that affect threatened and endangered species is required under the California Environmental Quality Act (CEQA). However, CEQA's stipulations for requiring mitigation are not as stiff as CESA's (Manthripragada 2006).

[4] In California, 134 HCPs have been approved and appear in the U.S. Fish and Wildlife Service (2010a) Conservation Plans and Agreements Database, Region 8. Many cover a single species for a short term (5 to 10 years), but many are large-scale multi-species regional HCPs.

more certainty for both developers *and* species protection was evidently needed. To promote development of large, continuous reserves for multiple species, California passed the Natural Communities Conservation Planning Act (NCCP) in 1991. The NCCP program coordinates development of regional habitat reserves for multiple listed and non-listed species, with a standard of providing for "recovery" of listed species, higher than the standard for take mitigation under ESA or CESA. The plans can cover more than 100 species and extend as many as 75 years.[5] The acreage included in NCCP and regional HCP plan areas in California comprises more than 25% of the total land and water area in the state (Fig. 2).

The NCCP is considered a national model for integrating economic development and conservation (for example, see Pollak 2001b). It was specifically designed to address planning challenges that climate change will exacerbate–namely the need to coordinate long-term, landscape-scale habitat conservation for multiple species with economic development. Although it is most commonly employed in an urban growth context, the NCCP process also has been extended to agricultural areas, forestlands, and aquatic ecosystems.

4.2 Water-related laws and programs

Certain water-related laws and programs also protect species and ecosystems, though indirectly. For example, the Army Corps of Engineers administers Section 404 of the Clean Water Act, which requires mitigation "to the extent possible" for activities that alter or harm existing wetlands. Motivations similar to those driving the development of HCPs and NCCPs have led wetlands managers to develop strategies to coordinate mitigation at a regional scale. For example, complaints about the ineffectiveness of piecemeal regulation under Section 404 led the Corps to coordinate some permitting regionally through Special Area Management Plans (SAMPs) in Southern California (Hopkins 2004). Integrated planning at the watershed scale has increased, to address water supply, quality, and habitat concerns simultaneously. This approach has been prompted in part by stepped-up enforcement of Clean Water Act provisions for stormwater runoff and for water quality standards applied to bodies of water. Also, market-based mechanisms have been introduced, such as "banks" for trading wetlands mitigation credits.[6]

4.3 Local governments and regional conservation planning

Ultimately, coordinated conservation efforts can succeed only when local governments are close partners, because local governments regulate general land use and development activity. With about 51% of all California land privately owned (Bunn et al. 2007), and many at-risk species dependent on privately owned habitat, city and county governments are among the most important decision-makers for conservation.

[5] NCCP plans are developed cooperatively by federal and state agencies, local governments, and private sector and non-profit stakeholders. There are 24 active, in-progress NCCPs (many of them HCPs as well) covering nearly 10 million acres; 8 have been approved and permitted (California Department of Fish and Game NCCP website, as of June 1, 2010).

[6] DFG has approved 52 conservation mitigation "banks" statewide, allowing for tradable offset credits, most for wetlands projects (California Department of Fish and Game 2010). DFG also oversees various incentive programs to promote conservation on private lands; about 43% of DFG-administered land is managed through easements, leases or other agreements with landowners (California Department of Fish and Game 2009).

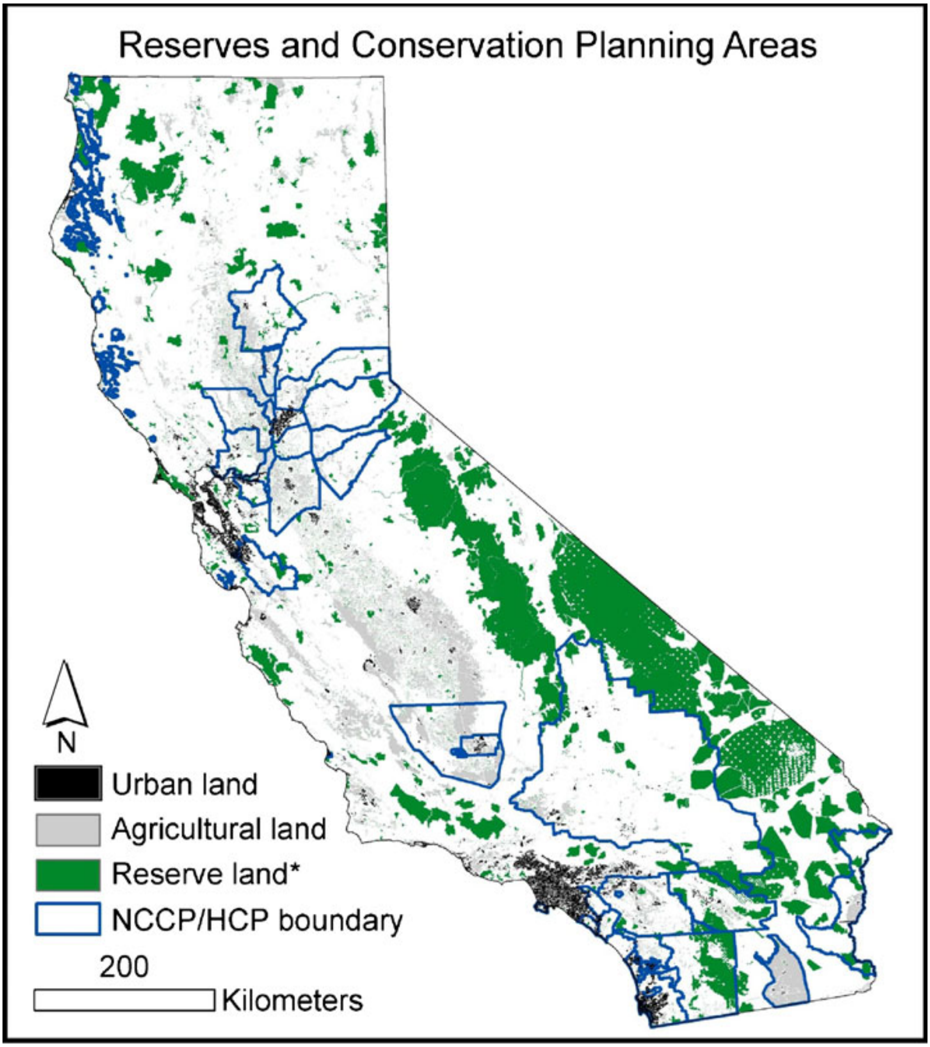

Fig. 2 Reserve and conservation planning areas in California. Source for land management status: California Department of Forestry and Fire Services: Fire and Resource Assessment Program. Source for NCCP/HCPs: California Department of Fish and Game. *Reserve lands include national and state parks, wilderness areas, private reserves and other areas where conservation is a primary management objective

However, without regional processes to provide a framework for local action, local governments' attention to conservation has been variable and sometimes inadequate (Bunn et al. 2007; Hopkins 2004). The main mandate for local governments to assess conservation impacts of development is the California Environmental Quality Act (CEQA). Under this law, local governments must analyze and, to the extent feasible, mitigate for negative environmental effects of proposed development projects, both for individual projects and for community development plans. On its own, CEQA has traditionally formed a weak impetus for local conservation activity.[7] CEQA has worked best when coupled with policy standards and objectives that can be translated into practical regulatory steps locally—such as through NCCPs (Landis et al. 1995).

In 2006, California passed landmark climate legislation, the California Global Warming Solutions Act.[8] Various state actions have been taken in response that affect land use planning. One action was the promulgation in 2009 of CEQA guidelines for analysis and mitigation of greenhouse gas impacts. However, the guidelines emphasize climate mitigation and not adaptation. In other words, they require analysis of effects of development projects on climate change, as opposed to the impacts of climate change on land use and development. In spite of this shortcoming, the required scrutiny of climate impacts of new development under CEQA may lead local governments to consider effects on habitat more carefully, especially if other regulatory standards, policies, and programs are in place that CEQA review can utilize.

One recent policy that links local action to broader environmental goals is Senate Bill (SB) 375. SB 375 was passed in 2008 to help implement the state's climate policies. The law calls on California's urban regions to develop coordinated plans for reducing greenhouse gas emissions through more efficient transportation and development patterns. Regional transportation agencies, in coordination with local governments, must now design "Sustainable Communities Strategies" (SCSs) to achieve mandated greenhouse gas emissions reduction targets from automobiles and light trucks. SB 375 establishes a detailed process for integrating development of land use, housing, and transportation plans. However, it does not align conservation planning with SCS planning in a similar fashion, requiring only that the regional agencies "gather and consider" information on resource areas and farmland. This shortcoming is a missed opportunity for the state to promote integration of economic and environmental goals.

Effective coordination would link various regional and local plans, such as for habitat conservation, watershed management, transportation, land use and development, and energy. An example of such coordination—and its potential for leveraging support—is the 2004 Regional Comprehensive Plan (RCP) developed by the San Diego Association of Governments (SANDAG). This plan integrates the region's NCCP plans[9] with regional plans for transportation, land use, water, energy, and other elements. County voters approved a ballot measure called TransNet in 2004 to extend a half-cent county sales tax increase for transportation improvements linked to the RCP. TransNet includes $650 million (in 2002 dollars) over its 40-year duration for transportation-related habitat mitigation, and $200 million for NCCP acquisition, management, and monitoring (San Diego Association of Governments 2006).

Few regions have gone as far as San Diego to integrate conservation planning with other land use and infrastructure planning processes. TransNet funding made possible the recent development of a regional management and monitoring program that identifies priority species for conservation, and stipulates monitoring at the regional, sub-regional, and project area levels. New habitat areas slated for acquisition are also slated to receive funds for ongoing management and monitoring at up to $5000 per acre annually. The greater

[7] The required conservation component of local "general plans" for community development often has been minimal, and adopted measures often have not been implemented. At the project level, environmental review has suffered from lack of capacity for evaluating cumulative impacts of individual projects (Bunn et al. 2007; Hopkins 2004).

[8] The Global Warming Solutions Act (AB 32, Nunez) calls for reducing greenhouse gas emissions to 1990 levels by 2020. In addition, Governor Schwarzenegger signed an executive order (S-3-05) on June 1, 2005, calling for even larger reductions by 2050, to 80% below 1990 levels.

[9] Six different sub-county NCCPs are being developed within San Diego County. Three have been adopted and are being implemented.

cohesion of planning efforts in the San Diego region can be explained by the convergence of certain factors, including institutional coherence (only one county, and 18 cities), intense development pressure within contained borders, and also the listing of species, particularly the coastal California gnatcatcher, that required "ecosystem thinking" in order to save. The recovery plan for the gnatcatcher required a plan to save coastal scrub habitat more broadly.

However, even as planning in San Diego County provides a model for multi-agency coordination, it also serves as an example of its limits. A recent lawsuit threw some San Diego NCCP permits into doubt because of jurisdictional confusion between the FWS and the Army Corps of Engineers regarding wetlands permitting for vernal pools (Krist 2007). Similar problems have plagued Riverside County's NCCP (Wheeler and Rowberry 2009). Lack of inter-jurisdictional coordination also has slowed implementation of the San Diego NCCP plans' adaptive management and monitoring program (Greer 2004; Hierl et al. 2005). In general, conflicting mandates and inter-jurisdictional coordination problems pose significant challenges for conservation planners (Craig 2010; Doremus 2001; Hatch et al. 2002).

4.4 Forest management laws and programs

California's large swathes of "working" forest are managed for both conservation and economic goals. On federal land, the Multiple-Use Sustained-Yield Act and the National Forest Management Act call for managing land for a variety of purposes, a goal which in practice has served to pit interest groups against one another (Nagle and Ruhl 2002). Timber harvest on private lands is governed by State Forest Practice Rules, with harvest plans reviewed and approved by the State Board of Forestry and Fire Protection in a process functionally equivalent to CEQA review. As with CEQA review more generally, the harvest plan review process has been criticized for its parcel-by-parcel approach to considering environmental impacts (Little Hoover Commission 1994). Some observers question the overall effectiveness of forest plan review in ensuring protection of wildlife and natural habitat (California Senate Office of Research 2002).

Two forces have reshaped California's forest and rangeland institutions since the beginning of the 1990s: the influence of the federal government through implementation of the ESA, Clean Water Act, and Clean Air Act, and the significant increase in local activism within forested and range watersheds (Fire and Resource Assessment Program 2003). Environmental groups have relied on ESA and CESA to try to direct forest policy toward managing for biodiversity (Nagle and Ruhl 2002). Some major conflicts have erupted, such as over listing of the northern spotted owl.

These forces have worked to promote more multi-party, landscape-scale and watershed-scale planning efforts. Many timber corporations have engaged in NCCP or HCP processes, a few of which have been extremely contentious (Krist 2006). Substantial coordination problems remain. These problems often relate to divergent mandates and priorities among state agencies; local governments in forested areas tend to be less engaged in HCPs/NCCPs than those in urban areas (Gaffin 1997; Krist 2006). Inter-agency conflicts have emerged, for example, between regional water quality control boards and the state's Department of Forestry and Board of Forestry regarding who and how to regulate impacts of timber harvesting on watershed health (California Senate Office of Research 2002; Fire and Resource Assessment Program 2003).

4.5 The state government's role

Although the State of California owns only 3% of the state's land area, it plays a significant role in conserving and managing natural resources areas via the above regulations and via funding. State funding for conservation and resource management activities comes from diverse sources, including special funds, park and water-related bonds, and the state's general fund. On a per capita basis, Californians spend more for natural resource programs than citizens of most other states, but less than in many western states facing similar water management issues (Gordon et al. 2007). However, much of California's resource funding goes to build and maintain infrastructure for human needs. The DFG considers conservation program funding in particular to be so low in the state as to constitute a "funding crisis," especially when it comes to resources for managing new lands under the agency's control (Bunn et al. 2007).[10]

Bond funding has played an increasing role in resource programs in recent years, enabling the acquisition of new habitat for protection. From 2000 to mid-2007, the state government spent over $2 billion for land acquisition and easements, mostly from resources bonds (Legislative Analyst's Office 2007). In November 2006, state voters added over $2 billion more (through passage of Proposition 84) for projects related to aquatic ecosystem restoration, protection, and conservation, including in forested areas. New bond funding caused expenditures for the state's Resources Agency to spike up starting in 2006–07, after stagnating in real terms since 2000–01 (Legislative Analyst's Office 2008). However, by 2010, few funds remained available for habitat acquisition, conservation, and restoration (Legislative Analyst's Office 2010).

Even as the state lacks a stable, ongoing funding source for conservation programs, it also lacks a clear policy framework for guiding expenditures or determining whether they are sufficient (Bunn et al. 2007; Legislative Analyst's Office 2003a). A multi-stakeholder effort called the Legacy Project was launched in the early 2000s to develop state conservation priorities, but it ran aground (Legislative Analyst's Office 2003a, b). The state's Natural Resources Agency released a *Climate Adaptation Strategy* in 2009, outlining steps for improving biodiversity and habitat conservation; prominent among these recommended steps is a process to establish priorities for allocating scarce resources for reserve acquisition, planning, management, and research (California Natural Resources Agency 2009). With natural resources under greater pressure from climate change, more dependable state funding is needed, but also more clarity regarding how to target funds.

5 Challenges and opportunities for adapting conservation to climate change

California faces the daunting task through the coming decades of preparing for and even aiding ecological transitions to manage and protect the state's rich natural heritage. Greater coordination will be needed across resource and land management sectors to address challenges and avoid conflicts. The uncertainty posed by climate change adds further complexity. Still, certain basic principles hold promise going forward: (i) following robust approaches to reserve design and prioritization, (ii) implementing adaptive management including ongoing experimentation with adaptive strategies, (iii) emphasizing co-benefits for climate change mitigation and adaptation, and (iv) enhancing ecosystem and economic health simultaneously through coordinated action.

[10] According to DFG's Lands and Facilities Branch, annual land operation management costs for many wildlife areas range from $16 to $100 per acre, with local agencies estimating these costs to be significantly higher. In 2005, the average level of support for DFG's wildlife areas and ecological reserves was $13 per acre, with one staff person per 10,000 acres (Bunn et al. 2007).

5.1 The challenge for conservation planning and resource management posed by climate change

Climate change poses formidable challenges. It will make ecosystems and species moving targets for planners, land managers, scientists, and regulators to understand and manage (Hannah and Salm 2005). Ecosystems as currently known will reconfigure, with higher risks to some species than to others.

Each species will respond differently to the diverse effects of climate change. As a result, planners and regulators face the challenge of anticipating and tracking multiple environmental conditions and species trajectories (Ruhl 2008). Some species, such as the Bay checkerspot butterfly, already may be doomed by isolation in fragmented spaces that will become increasingly unsuitable with climate change; efforts to save them from extinction by conserving current habitat may prove futile (McLaughlin et al. 2002). Other species may see some populations or subspecies at increased risk of extinction, while others are able to persist in "refugia." For example, the rabbit-like pika, which inhabits mountain-top "islands" of the Sierra Nevadas, may face local extinction because of temperature effects of climate change in sites without adequate rocky talus habitat that provides refuge from the warming (Beever et al. 2003; Millar and Westfall 2010). Meanwhile, some species may actually thrive as a result of climate change, even posing a threat to other species they encounter as they expand their ranges. Some species not yet in severe decline may depend on proactive strategies to maintain habitat or facilitate migration to new habitat.

The scientific and practical challenges of assessing species' shifts are daunting. Conservation scientists and managers have always had to contend with uncertainty and change in the natural environment—for example, dealing with fire, flood, and drought. However, climate change cannot be treated as just another disturbance regime that forms part of a resilient, persistent ecosystem (Ruhl 2008). Climate change is putting chronic pressure on ecosystems at a rate and magnitude that management organizations have not before experienced. Therefore, basing management decisions on historical environmental variability or recent experience is inadequate (Millar et al. 2007). Instead, ongoing evaluation of existing and potential future effects of climate change on ecosystem and species health is also necessary.

To enable such assessments, more locally detailed information on climate change scenarios is critical. However, while output from models that "downscale" projected global climate change to local levels is becoming available (Cayan et al. 2008; Maurer et al. 2007), models do not capture fine-scale microclimates or address the complex interplay of local economic and environmental pressures on species and ecosystems of concern. For example, nonlinear feedbacks may be important locally, and risk thresholds may be hard to pinpoint, limiting the ability of models to guide management decisions (Ruhl 2008).

The governmental coordination challenges are also daunting. As climate change alters the natural landscape, species decline cannot be framed mainly as a local problem with local solutions. The very concepts of "conservation" and "restoration" of local habitat areas need to be reframed. Strategies and techniques will be needed that integrate multiple resource and planning elements at multiple scales in space and time. To assess and address threats, planners must consider not just consequences of current economic activity on current natural habitat, but risks to species' future habitat needs from such activity, including human adaptive strategies. Similarly, land managers must integrate consideration of changing demands for water, timber, recreation and other ecosystem services (including use of ecosystems for carbon storage) into assessments of the impacts on ecosystems.

Coordination will be necessary to avert conflicts between environmental and economic uses of natural resources. Such conflicts have already become acute in some parts of the state; with climate change, the conflicts may worsen. A salient example is demand for water from the Sacramento-San Joaquin Delta. In this case, court-ordered water delivery for environmental purposes, flood management challenges (which will worsen with climate change), and water supply and storage needs (also affected by climate change) drive the need for more coordinated solutions. Recent court rulings have mandated that FWS consider climate change and its impacts on endangered species when considering impacts from water management plans affecting the Delta (NRDC v. Kempthorne 2007; Pacific Coast Federation of Fishemen's Associations v. Gutierrez 2008), providing even more impetus for stakeholders to increase coordination. Similarly, housing development already threatens scarce natural habitat in many parts of California (Bunn et al. 2007); legal conflicts may intensify if more species are designated as threatened or endangered under state and federal law due to effects of climate change. More coordinated land use planning, such as called for under SB 375, could help to anticipate and resolve these conflicts.

Thus, climate change strengthens the imperative for coordinated planning across resource and land management sectors and agencies. Yet climate change also presents formidable challenges for achieving the necessary coordination.

5.2 Principles for adaptation strategies

Although specific impacts of climate change for individual locations and species are highly uncertain, there is increasing confidence in expected impact types. Going forward, basic principles for sound reserve design may provide some basis for adaptive strategies. However, the need to take action soon to avert risk must be balanced against the need to develop more specific knowledge and strategies for particular species, species groups, and ecosystems. Tension between these two basic strategies is not actually new for conservation planners, who have long faced a trade-off in prioritizing resources for reserve acquisition versus ongoing information-gathering and management (Wilhere 2002). Climate change only strengthens the imperative for pursuing both short- and long-term strategies.

Basic impact types expected due to climate change include species range shifts that track the climatic envelopes to which species are accustomed, increased fire hazard due to changes in plant productivity and moisture deficits, increased risk of extinctions for endemic species and species with fragmented habitats, disruption of species associations where synchrony of biological events (for example, flowering date with pollinator emergence) relies on multiple diverging environmental cues, and acclimation or evolution of many species to tolerate new conditions (IPCC 2007; McCarty 2001).

5.2.1 Robust principles for reserve design

Principles already advocated for sound reserve design may provide some basis for adapting conservation strategies to these changes. For example, biologists promote large, continuous reserves for multiple species as more sound than piecemeal strategies addressing species' needs individually (Christensen et al. 1996; Groves et al. 2002). In the face of climate change, systems of reserves encompassing climate variation in the landscape (e.g., topographic variation) and corridors connecting reserves (e.g., high-low elevation and north–south latitudes) will enable species to migrate shorter distances, or through more hospitable terrain (Ackerly et al. 2010; Heller and Zavaleta 2009). Protection of reserve boundaries and genetically diverse, evolutionary "hotspots" will reduce external pressures and maximize species capacity to adapt to change. Thus, robust design principles include strengthening fixed elements (reserves) as well as connectivity among reserves, and limiting external pressures, such as pollution, that will act synergistically with climate change (Hannah and Hansen 2005). California's *Climate Adaptation Strategy* recognizes these principles as critical for implementing its central strategy—to create and maintain a network of reserve areas to provide refuge and aid the movement of species (California Natural Resources Agency 2009).

Yet even if it relies on robust design principles, stepped-up reserve acquisition will still also require a process to prioritize investments and manage outcomes. With climate change, that process will benefit from improved knowledge regarding ecological transitions and impacts. Conservation planners and managers need increased capacity to assess and plan for climate risks in order to credibly define conservation and restoration targets that are responsive to changing biophysical conditions (Hannah et al. 2002; Harris et al. 2006).

5.2.2 Integrating management and planning for adaptation

Setting, achieving and re-evaluating conservation goals will require a greater commitment to science-based "adaptive management," which calls for ongoing experimentation and re-evaluation of strategies in light of experimental results and priorities (Lawler et al. 2010). Responsive management will require concerted efforts to manage climate-related transitions. A diverse "toolbox" of approaches could be employed, with strategies varying depending on the species, objectives and pressures in a given system and point in time (Millar et al. 2007).

Millar and colleagues have identified three general approaches for managers to consider: (i) create resistance to change, (ii) promote resilience to change, and (iii) enable ecosystems to respond to change. The first two of these are short–term options; ultimately, species and ecosystems will respond to climate change, and managers will have to decide how to facilitate adaptive responses to ongoing change. Tools might include actively assisting transitions in species' ranges (for instance, through "assisted colonization" or "managed relocation"), enhancing redundancy in the face of uncertain outcomes (for instance, planting in multiple environments), responding to widespread mortality events with an eye to the future, and experimenting with promoting diversity in potential refuge locations where species are more likely to survive a transition (Millar et al. 2007). Utilizing non-local genetic material (e.g., from further south) in restoration might also enable a species to persist in its current habitat when conditions no longer permit the local genotype to flourish (Harris et al. 2006). Natural resource and reserve managers, like conservation planners, should seek to maintain or increase the connectedness of the landscape, and consider the future in restoration efforts (Vasey and Holl 2007).

Conservation planners and managers also will need to develop assessment indicators and management goals that do not depend on current habitat structure or distribution. Assessments of habitat quality should shift toward a multivariate suite of ecosystem health indicators that do not depend on current constellations of species in any given site, but instead ensure the adaptive capacity of the system. For example, indicators could focus on presence of intact food chains and diversity at multiple scales, including diversity in species and ecosystem responses to perturbations (Elmqvist et al. 2003; Vasey and Holl 2007). Diversity at the genetic scale is important because it provides the raw material for biological adaptation to novel conditions, while at the scale of species and functional groups (groups of species that perform similar ecological functions) diversity provides a level of insurance against effects of environmental variability and access to a wider pool of resources. The more diverse the portfolio of genes, species, functions and responses to change, the more resilient an ecosystem is likely to be to changing conditions (Elmqvist et al. 2003).

Further, establishing a goal of maintaining an ecosystem that is resistant or resilient to fire and invasive species might supplant a goal of maintaining a particular species list in a given site. To achieve this new goal, it may be necessary to increase emphasis on non-reserve land management or restoration (e.g., through local zoning changes or resource management partnerships) to reduce pressures from invasive species and human fire ignitions. Lower levels of predictability may need to be accepted (i.e., targets with less certain consequences for current species and habitats) to accommodate increased variability or directional system change (Hughes et al. 2005).

This new generation of indicators for species and ecosystem health could help guide the process of adapting conservation management strategies to changing conditions. Yet, while desirable, widespread and intensive adoption of adaptive management techniques may currently not be realistic for resource agencies with limited scientific capacity and staff, and with limited public support. A more robust planning and governance structure for promoting adaptive management is required. In this structure, scientists will need to engage at all levels in the often messy and incremental political processes by which conservation strategies are developed, implemented, and evaluated (Christensen et al. 1996).

5.3 Achieving co-benefits by linking mitigation with adaptation

Climate change presents a daunting challenge for conservation planners and resource managers. However, at the same time, it also presents opportunities. In some cases, the adaptation strategies needed to help ecological systems cope with upcoming changes can produce co-benefits by helping reduce greenhouse gas emissions and by promoting economic efficiency. Techniques can be utilized to identify trade-offs among planning objectives as well as potential co-benefits, or win-win scenarios, in aligning climate mitigation and adaptation strategies, and conservation objectives with other natural resource objectives.

One promising technique is scenario modeling, through which conservation and resource planners consider alternate planning and investment scenarios in relation to their projected outcomes, such as for availability and demand for land, water, and energy. Such modeling is currently being used in state water planning, reflecting the intense pressure on water resources. Scenario modeling is also being employed by regional planners to estimate potential energy and cost savings from policies to promote more efficient transportation and land development. Scenario modeling is the basic tool employed by climate change scientists as well.

Comprehensive scenario modeling should explicitly include climate change adaptation and mitigation measures. In this way, costly mistakes, such as development in floodplains or critical land corridors needed for species migration, might be avoided. Co-benefits may be identified, such as opportunities to maintain or restore floodplains that simultaneously address habitat, flood control, and water storage needs (such as through conjunctive management with aquifers and surface reservoirs). At the metropolitan scale, similar win-win outcomes could be identified, for example if compact "infill" development near transit stops simultaneously helps reduce greenhouse gas emissions, transportation infrastructure costs, and habitat destruction and fragmentation.

One successful example of integrated planning that addresses climate change is a project to restore tidal marsh habitat along the southern edge of the San Francisco Bay, led by the South Bay Salt Pond Restoration Project (www.southbayrestoration.org). The project aims to improve flood management for nearby communities threatened by sea level rise, while restoring habitat for native and migratory species. More generally, efforts to apply such integrated water planning tools in California are often hampered by the lack of clear jurisdictional authority over floodplains and groundwater (Bunn et al. 2007).

5.3.1 Achieving co-benefits in the forestry sector: carbon sequestration

In forest management, strategies to promote carbon retention and uptake present another opportunity for combining mitigation of climate change with adaptation (Millar et al. 2007; Wayburn et al. 2007). Such strategies include promoting markets for carbon sequestration through reforestation, afforestation, and forest management for conservation. The win-win opportunity presented by a carbon market could make larger-scale protection of intact ecosystems viable in some locations and help prevent fragmentation and other pressures hindering species survival. However, forestry policies promoting carbon sequestration need to be adaptive and promote long-term ecosystem health, lest they risk producing unsustainable outcomes.

In 2007, California became an international leader by establishing protocols for carbon accounting from avoided deforestation, reforestation, and conservation-based forest management, through the California Climate Action Registry.[11] The protocols incorporate some key principles for achieving carbon benefits while enhancing ecosystem and species health. In particular, qualifying projects are to be secured on a permanent basis, and they must promote “natural forest management.” Managing forests for diversity and complexity at a landscape scale improves their resilience, or their ability to absorb change and bounce back to their previous condition, while providing co-benefits for biodiversity and watershed function (Wayburn et al. 2007). Such policies are needed to prevent a narrow focus on rapid carbon sequestration, for example through use of plantations of rapidly growing trees, which provide little in the way of habitat for other species (California Air Resources Board 2007; Wayburn et al. 2007).

To fully achieve co-benefits, policies promoting sequestration must themselves be adaptive. As climate change stresses forests, the importance of managing for resilience and adaptation will affect sequestration strategies. Species selected for reforestation projects should be viable for at least decades under changing climate conditions. Similarly, steps should be taken to ensure that forests protected from harvest to retain carbon are not vulnerable to increased fire from climate change, lest their value as a carbon sink be compromised. Promoting longer rotation periods between harvesting, and variable harvesting within forest stands, could enhance overall forest carbon sequestration as well as ecosystem benefits (Wayburn et al. 2007).

6 Is the state’s governance framework up to the challenge?

California has made advances that will help conservation and resource management adapt to climate change. The California Natural Resources Agency’s *Climate Adaptation*

[11] See http://www.climateregistry.org/PROTOCOLS/FP/. The forestry protocols require that pertinent carbon reductions must be in addition to what would have occurred in the absence of a carbon market, and that qualifying projects commit to best management practices, to maintaining and promoting native forest types, and to supporting natural forest management (California Air Resources Board 2007). Qualifying projects must be secured with a permanent conservation easement to a qualified third party, a conservation not-for-profit organization, or a state or local government entity.

Strategy, released in 2009, includes strategies for biodiversity and habitat adaptation. A statewide mapping project to identify critical habitat linkages also has recently been completed. The California Energy Commission's Public Interest Energy Research program has funded climate impact assessments highlighting challenges for ecological systems and their management. Finally, certain state programs—notably the NCCP program—are starting to incorporate climate change and long-term "adaptive management" strategies that should aid in responding to climate change.

However, more concerted attention is needed to address the substantial threat and uncertain changes posed by climate change. Basic goals of conservation planning and resource management (such as maintaining or restoring historic habitat conditions) and common practices (such as relying on focal species as indicators of ecosystem health) need to be reexamined or reoriented. More strategic action and incentives are required to support coordinated planning.

6.1 Strengths and limitations of the state and federal endangered species acts

As more species are threatened by climate change, ESA's and CESA's roles in preventing extinction will remain useful. As current ecological communities disassemble, the laws' focus on individual at-risk species will help propel efforts to understand their unique needs. In the aggregate, the laws provide some assurance that the state's growth and development, including human response to climate change, will not be achieved at other species' expense. Furthermore, the regulatory "teeth" of ESA and CESA have motivated the arduous process of coordinating plans such as NCCPs; it would not be simple to devise and enact a suitable replacement for that mechanism.

Scientific data related to the potential effects of climate change on species is becoming a requirement in the ESA consultation process. Recent court decisions have found that the FWS must use data on the impacts of climate change in developing biological opinions related to federal agency actions, for example, in the case of California's endangered delta smelt (NRDC v. Kempthorne 2007). Further, Section 7 of the ESA also compels federal agencies to carry out conservation programs to advance the goals of the ESA. This provision could surely be leveraged to develop forward-looking conservation efforts to reduce the risk of species endangerment as a consequence of climate change.

Yet while ESA and CESA may remain necessary, they will not be sufficient for achieving conservation goals in the face of climate change. In some ways, they could even be counter-productive. Climate change amplifies existing inadequacies of the ESA and CESA, such as their reactive nature and limited scope, and could force regulators and managers into impossible choices. The laws' stiff prohibitions against take apply only after species are already at risk, often after habitat has become so degraded that restoration is difficult. The process for listing a species is typically undertaken in response to measured severe declines in known populations. For example, in denying the petition to list the pika as endangered by climate change, the California Fish and Game Commission commented that prior decisions to list other species were taken partly in response to data showing "dramatic and measurable declines" in the species (California Fish and Game Commission, April 7 2010). This comment reinforces the notion that the CESA cannot be leveraged for species protection unless decline is already severe, as opposed to anticipated in response to changing climate.

In the face of risk and rapid change, ESA and CESA may hamper efforts to target resources where they might be most effective. Difficult trade-offs may arise between strategies for different species, for example, if efforts to aid a listed species through managed relocation negatively affect other species, or if resources spent to recover a listed species threatened by climate change preclude more certain protection of a non-listed species. For example, the FWS, which also declined to list the pika in 2010, contended that the availability of rocky talus "refugia" within the species' current range, and the ability of the species to modify its behavior to gather food during cooler times of day, would enable it to survive a warmer climate (U.S. Fish and Wildlife Service 2010b). This conclusion suggests that protection of these refuge habitats may be important to preventing listing of the species, but the ESA and CESA provide a weak impetus to direct resources toward such efforts.

Potentially tough legal questions lie ahead. For example, CESA protects not only endangered but also threatened species—those likely to become endangered "in the foreseeable future." When should species for which scientific models project impending climate-related threats be listed? What mitigation is appropriate regarding projected future habitat needs of at-risk species? For species that face extinction because of temperature effects of climate change, the proximal cause is diffuse, and so ESA and CESA may not be useful levers for protection (Ruhl 2008). Instead, ESA and CESA take prohibitions may prove most valuable in preventing discrete, more easily attributable actions that threaten species survival.

6.2 Strengths and limitations of NCCPs for addressing climate change

More proactive conservation programs, such as NCCPs, may be better venues for adaptation planning than the traditional reactive approach to implementing the ESA and CESA. However, even these programs will face challenges given their current regulatory frameworks.

NCCP law imposes standards for scientific review, biological reserve design, and ongoing reserve management that will help in adaptation.[12] Furthermore, the NCCP focus on ecosystems and multiple species, including non-listed ones, provides some capacity for managing future needs of species and ecosystem health. With their long time frames and broad stakeholder engagement, NCCPs may be able to leverage support for adaptation measures that extend spatially beyond current habitat of covered species. The plans impose a recovery standard for covered species higher than under ESA or CESA, which introduces the opportunity for considering climate change in acquisition and restoration efforts.

Recently initiated NCCP plans will include climate change as a foreseeable "changed" circumstance, reflecting the law's requirement for utilizing the best available science. This provision will make climate-induced effects on species subject to remediation through stipulated measures. Newer NCCP planning processes are utilizing dynamic models and maps, considering novel combinations of species, and in general, attempting to define robust strategies for reserve acquisition and management.

Many NCCP participants believe that at least some NCCP programs are gaining traction. For example, in a recent survey of NCCP experts, a majority of the biologists (of 12

[12] NCCP plans must be reviewed by independent scientists, although only as an initial input into plan development and approval. Reserves are required to be large-scale and to provide for diverse landscape gradients and corridor linkages within and beyond their boundaries—design elements all likely to aid species transitions. NCCPs must conserve the ecological integrity of large habitat blocks, ecosystem functions, and biological diversity—although these terms have not been defined in statute. Adaptive management programs must be implemented to "use the results of new information gathered through the monitoring program of the plan and from other sources to adjust management strategies and practices" (California Fish and Game Code § 2805).

surveyed) and environmental advocates (of 14 surveyed) indicated that they believe that NCCP plans rely on sound science and are a good approach to preserving biodiversity (Barrows 2007). A majority of biologists also indicated that NCCP regulations are sufficient to protect species and habitat.

Nevertheless, NCCPs face a series of obstacles and constraints that have often undermined their effectiveness. The most fundamental obstacle hampering NCCPs, which helps explain all other shortcomings, is lack of adequate funding; inter-jurisdictional and political conflicts form another substantial challenge (Barrows 2007; Cylinder et al. 2004; Greer 2004; Hierl et al. 2005; Krist 2007; Ruhl 2005; Wheeler and Rowberry 2009). NCCPs and HCPs have also been criticized for inadequate scientific oversight, adaptive management, and monitoring (Camacho 2007; Barrows 2007; Opperman and Bernazzani 2003; Pollak 2001a, b; Rahn et al. 2006). For example, the San Diego NCCP—the state's oldest plan, approved in 1996—has reorganized its management and monitoring program in response to such criticism, including from the California courts (Greer 2004; Hierl et al. 2005; Krist 2007).

NCCPs have suffered from chronic funding problems, and this issue will only be amplified in relation to adaptation needs. In spite of its innovative approach to funding (through TransNet), the San Diego NCCP process still has only secured about half the funds needed to fully implement its goals. The viability of another ambitious NCCP process, in Riverside County, has recently been called into question due to escalating costs for land acquisition (Wheeler and Rowberry 2009). Both the San Diego and Riverside County processes are now estimated to require full funding at a level above $4 billion each.

As species migrate in response to climate change, inter-jurisdictional coordination within and among NCCP plan territories will also be critical for adaptation strategies to work. A promising sign is the emergence of some coordination efforts, such as the South Coast Missing Linkages Project (www.scwildlands.org). This project identified 11 priority areas linking existing reserves, and encouraged NCCP planners to adopt supportive policies. The linkage designs were developed based on habitat and movement needs of multiple focal species. Ten of the 11 linkages are being actively implemented (Spencer et al. 2010).

A state-level *Essential Habitat Connectivity Project* was recently completed by consultants for the state's Department of Fish and Game and Caltrans—the state's transportation department (Spencer et al. 2010). This mapping project was funded by the Federal Highways Administration, giving some indication of both the importance of such a project for infrastructure planning purposes, and also of the lack of funding sources from within the state's Resources Agency. The project developed a systematic method for identifying critical linkages among existing reserves in California, but it did not develop a method for modeling climate impacts, nor has an implementation program been established to ensure that the mapped linkages are translated to action on the ground.

Another challenge for the NCCP approach, in the context of climate adaptation, relates to the basic incentive structure. NCCPs are essentially coordinated permitting processes that have been leveraged into a tool for conserving ecosystem health over the long term. Private landowner contributions for reserve acquisition and maintenance are secured through "no surprises" assurances, but climate change will introduce many new surprises. The basic contractual premise—to secure and restore ecosystem-scale habitat for natural communities over a long duration—depends on a connection between individual species and ecosystem health in a given place. This premise will be challenged by climate change if current species assemblages start to disintegrate. As a practical example of the problem, NCCPs often rely on monitoring indicator species as a proxy for ecosystem health, and also the reverse, namely monitoring habitat as a proxy for species health. Such rule-of-thumb methods may become less reliable.

Thus, climate change may challenge basic premises of the NCCP approach by rendering more tenuous the assumed link between current assemblages of species and given habitat areas. As this occurs, NCCP managers may be forced to focus more on their primary regulatory mandate—namely, to ease transitions for individual, listed species—and forego opportunities to manage for a broader suite of ecological values. Alternately, they may find themselves managing habitat reserves with historical boundaries developed for groups of species that no longer thrive in the changed environments.

6.3 Need for stronger state and regional planning frameworks

Finally, the lack of an overarching state framework for identifying and implementing conservation priorities across private, state and federal lands is a serious impediment to adaptation. Wider-than-local solutions are becoming more important, and the inter-jurisdictional coordination problems that have hampered habitat planning and resource management must be addressed. More integrated solutions are needed across resource sectors, for example, to ensure that NCCP plans consider likely future changes in land use patterns, water availability, and energy use, while regional transportation and land use plans also incorporate NCCP objectives. The state government plays a decisive role in determining whether such coordinated planning is undertaken across programs and agencies.

7 Directions for conservation and management

Protecting the state's rich natural heritage while aiding ecological transitions through coming decades will be a daunting task. Given that adaptive management for climate change effects is still in its infancy, with experimentation required to determine how to proceed, regulatory responses also will need to be adaptive. Flexibility is needed, especially because there are tensions—mostly healthy ones—between basic strategies, such as the need to avert risk by reserving land soon for natural habitat, and the need for more research and better management of existing reserves and multi-use lands. To coordinate a flexible, responsive set of policies and programs over time and across all parts of the state, stronger leadership from the state government will be required.

7.1 Establishing state-level priorities

A state policy framework to coordinate conservation in the face of climate change will need to identify and address priorities for reserve land acquisition, research and management needs, and provide incentives and opportunities for coordinated conservation efforts across jurisdictional boundaries. At the most fundamental level, a stronger state policy framework will need to begin by clarifying basic values and goals of conservation policy. The traditional goal enshrined in ESA and CESA—to prevent the extinction of species—remains valid, but it very likely has already been rendered unachievable for many species by human-induced climate change. Even if preventing extinction, to the degree possible, remains the over-arching goal going forward, that goal makes it irresponsible to allow the reactive mechanism of take prohibitions and subsequent conservation efforts to drive policy choices by default, regardless of the costs, conflicts, and consequences for species resulting from lack of forward-looking planning. But if prevention of extinction is not possible for many species, what conservation goals should be added or substituted? How can policymakers identify the most promising strategies and distinguish trade-offs among them for assisting various species and maintaining healthy ecosystems?

A state agency-stakeholder process can help in clarifying policy and program goals for protecting California's biodiversity. The California Natural Resources Agency initiated such a process in developing the state's *Climate Adaptation Strategy* (California Natural Resources Agency 2009). The strategies for biodiversity and habitat protection it recommends align with many of our conclusions, including the critical need to establish a system of priority habitat reserves and to provide for connectivity for species movement.

As the state's adaptation strategy moves forward, attention should be paid to clarifying basic goals to help frame choices. Should a state adaptation strategy aim to save as many species as possible from extinction? To preserve "representativeness" of California's natural communities and species types? To ease species transitions as much as possible, especially by ensuring that economic activity does not interfere?

After clarifying goals, the next step in developing a more coordinated approach to adaptation will be to define and prioritize program objectives. In effect, the new framework must successfully encompass and integrate place-based and species-based strategies for conservation planning and resource management. These are the objectives of the NCCP program; going forward, what is needed is a state commitment to implementing the NCCP principles at a broader geographic scale and with the agility to respond to changing climate. NCCPs and HCPs should no longer be treated mainly as isolated reserves, but rather as part of an integrated system of reserves managed flexibly in response to adaptation needs.

Only the state government can provide the necessary degree of coordination and resources for this to happen. State-level action will be necessary to ensure that: (i) places are singled out for protection that will retain or acquire value as habitat for resilient natural communities and self-sustaining ecosystems, and (ii) strategies to aid species that require action across jurisdictional borders receive support. The state took an important initial step towards making this coordinated approach possible by completing the *Essential Habitat Connectivity Project* in February 2010 (Spencer et al. 2010).[13] However, this mapping project must be translated into implementation plans on the ground.

In terms of immediate priorities, given the rapid rate of climate change (compared to institutional abilities to keep pace) it may be practical to prioritize reserve acquisition by relying on basic, robust design principles. From this perspective, the more large-scale preserves with environmental variability, the more likely the state's flora and fauna will weather the changes ahead. However, effectively managing risks via stepped-up reserve acquisition also requires directing state resources where they will be most effective at achieving conservation objectives. Thus, the state also must provide greater support for scientific research to identify priority reserve lands, and then continually seek to improve management and acquisition strategies in light of new knowledge.

New, adaptation-oriented performance indicators should be identified to assess progress toward goals and priorities. Managers will need to implement strategies for monitoring species not dependent on current habitat, and for habitat quality not dependent on current species groups, but instead focused on quantifying impacts and adaptive capacity. Such indicators might address diversity, functional redundancy, or other resilience measures (Groves et al. 2002). An initiative that may hold promise for this purpose is the state

[13] The Essential Habitat Connectivity Project was mandated through passage of Assembly Bill 2785 (Ruskin) in 2008. That statute mandated the Department of Fish and Game to identify and compile a database of California's most critical areas for maintaining habitat connectivity, including wildlife corridors and habitat linkages.

agency-led Environmental Protection Indicators for California (EPIC) project. Since the early 2000s, the project has worked to identify and monitor 84 indicators of environmental quality (including climate-related variables such as air temperature and sea level rise) and ecosystem and species health (Office of Environmental Health Hazard Assessment 2004). When such indicators constitute policy targets, rather than just measures of direction for environmental trends, they can be useful as a basis for state program and budget choices (Legislative Analyst's Office 2003a). However, many EPIC indicators are still under development or not monitored systematically. The project has brought to light significant data gaps for many environmental attributes (Legislative Analyst's Office 2003a).

In the forestry sector, the state should ensure that carbon sequestration policies are adaptive and promote ecosystem health. For example, species chosen for individual reforestation projects should be viable over substantial time periods, and eligible projects should be held accountable for risks of carbon removal such as through fire, disease, or other unplanned events. This might be accomplished by requiring within-project mitigation plans or insurance policies (California Air Resources Board 2007). Another way to link climate mitigation with conservation would be to consider protection of stored carbon an important factor in prioritizing sites for conservation dollars.

7.2 Adaptation emphasis in applying federal and state laws

Existing laws and regulations may require some modification to better orient them to adaptation needs. Changes might include mandates that NCCPs and related recovery plans address climate change effects. In addition, adding stepped-up requirements for periodic review by independent science advisors, and incentives to reward NCCP permit holders for long-term performance in relation to plan goals, could make NCCP implementation more adaptive. Incentives might include requiring permit holders to post performance bonds as insurance for plan effectiveness and rewarding permit holders who provide reliable information or effective strategies benefiting a species, even if it means modifying management strategies as a result (Thomas 2000; Camacho 2007).

To encourage NCCP planners and managers to develop indicators and to monitor and manage for resilient ecosystems, some modifications to the NCCP regulatory framework may be needed, because, as noted earlier, the current regulatory hammer—to support recovery of plan-covered species—may be problematic as a forcing mechanism. One approach would be for lawmakers to add language to the CESA improving on Section 7 of the ESA, to require that state agencies develop forward-looking programs for species protection, and consider the best available scientific data, including climate change impacts, when evaluating the environmental impacts of any action.

To support development of strategies for aiding at-risk species, increased emphasis and funding should be directed toward recovery planning and designation of "critical habitat" in a more flexible and adaptive manner than in recent practice. FWS (in consultation with DFG) is supposed to develop these plans, but the agencies complain about chronic underfunding of this work. Recovery plans have been approved for fewer than half of the state's listed species. The agencies have discretion over the resources directed toward recovery plans. They might employ this discretion to favor plans that incorporate adaptive definitions of habitat, or species with better chances of survival, or habitats deemed critical to protecting ecological function in reconfigured natural landscapes (Ruhl 2008). At the same time, the agencies could make use of the recovery plan process to assess co-benefits, such as for carbon sequestration and ecosystem services (Ruhl 2009). Considering these factors could aid the state in weighing trade-offs and achieving broader goals more efficiently.

Ultimately, a strategy is needed to promote ecosystem resilience that is not so dependent on the listing of endangered and threatened species as a forcing mechanism. Whether through NCCP law or another venue, the state should support the development of habitat conservation plans even in areas that are not home to listed species. The pro-active development of such plans is essential to help the state foresee and address future needs of species not currently listed.

At the same time, the process for developing such plans should be integrated with the processes for developing other regional plans, such as SCSs under SB 375. As it stands, SB 375 requires only that SCSs recognize existing NCCPs, but not that new NCCP plans be developed and integrated with other processes. Amending CEQA to require review of adaptation needs and impacts could help prod this larger coordination process along. However, robust state support for developing habitat plans in all regions is a necessary prerequisite for this greater planning integration to succeed. The transportation agencies responsible for SB 375 have neither the means nor the capacity to develop NCCPs across the state.

7.3 Institutional support for program implementation

A stronger institutional framework is needed to carry out these objectives. Building on the statewide *Essential Habitat Connectivity Project*, an implementation program could be established to provide overarching guidance that smaller-scale plans could fit into. This sort of program could help in identifying whether certain NCCP/HCP plans and programs should be merged or coordinated, based on climate-induced transitions. It could help implement acquisition strategies and align them with other state and regional planning efforts, such as for integrated watershed management and for urban development under the SB 375 process. Finally, it could help align public land management strategies for addressing climate change, such as between state and federal parks.

A more effective institutional structure for conservation planning would include not only greater coordination of NCCP plan development and preserve acquisition, but also a more systematic approach to adaptive management. A "learning infrastructure" for adaptive natural resource governance must be institutionalized (Camacho 2009). Effective models for an ongoing, systematic approach to adaptive management and planning should be sought and emulated. One such model comes from the transportation planning arena. For decades, regional transportation agencies have been required to conduct a "comprehensive, cooperative, and continuing" planning process for updating their investment plans. In a rolling fashion, the agencies fold new funds into their long-range (minimum 20-year) plans, modeling the projected effects of new policy and investment choices in relation to indicators for air quality, mobility, accessibility, affordability, and other factors. This ongoing, iterative process forms the basis for SB 375's mandate for regions to develop Sustainable Communities Strategies (SCSs) to reduce greenhouse gas emissions.

Another institutional buttress for strengthening adaptation would be to expand the efforts of the biennial statewide assessment of climate impacts, to provide the latest scientific research on impacts and adaptation to aid resource managers and conservation planners. To be most successful, such a process should engage both social scientists and resource managers to jointly address the challenges (Heller and Zavaleta 2009). In conjunction with a more coordinated reserve acquisition and management framework, such a science-focused assessment process could help link scientists to on-the-ground needs and help land managers develop future-oriented plans for aiding specific species' transitions.

7.4 Financial resources

To make these strategies possible, more funding will be needed. The state government should identify an ongoing revenue stream to support adaptation planning. Revenues from a state cap and trade program or regulatory fees for greenhouse gas emissions could provide such funding. Fees for state review of CESA and NCCP permit compliance could provide another source. Additionally, a state bond measure, revolving loan fund, or trust fund might be utilized to raise and allocate revenue for acquiring and managing habitat for ecosystem values (Camacho 2007; Wheeler and Rowberry 2009).

Finally, private landowners and others whose actions affect valuable habitat may need to support adaptation. In doing so, it would be inappropriate to require that they mitigate for climate-induced effects on species that cannot be attributed to their specific actions. Because the causes of climate change are diffuse and attributable to very widespread behavior, it is proper that the public at large bear costs for adaptation. Still, if specific landowners or other organizations (such as utility companies or agricultural businesses) seek to enter into long-term contracts with the state or local governments for the use of natural resources—such as utility or water contract renewals—then they could be required to mitigate not just for current habitat needs of at-risk species directly related to their actions, but future needs as well. Determining the nexus, however, may be difficult.

It should be recognized that forward-looking, comprehensive planning holds some promise for raising funds and reducing the cost of adaptation. For example, regions that pursue coordinated planning could emulate the San Diego area example by folding NCCP funding into their local tax measures. Furthermore, a well-planned NCCP can take advantage of current cost savings in land acquisition—compared to anticipated higher costs in the future—by borrowing against that cost difference to fund acquisition sooner rather than later. San Diego made use of this mechanism in funding habitat acquisition through TransNet.

8 Conclusion

California stands at a painful transition point; ESA and CESA take prohibitions express an ethical commitment to preventing extinction of other species, but because of human-induced climate change, some species likely have already been condemned to extinction. California's natural resource agencies already face diverse and often competing mandates to protect species and ecosystems while providing for economic uses. Now they must examine their assumptions and practices in light of changing climate. Uncertainties abound, leaving managers to address species and ecosystem needs without a clear way to judge likely outcomes.

The state's new adaptation strategy for biodiversity and habitat is a promising step forward. The proposed strategies align closely with the recommendations in this article. However, they will have to be translated into concrete policy measures and receive adequate funding for the challenges to be addressed. The "ecosystem thinking" that the NCCP promised has not been fully realized, and yet a greater commitment to that principle is now required. There is no longer time for delay in implementing a more concerted adaptation governance strategy. Climate change is underway in California, and state laws and institutions must adapt. In order to renew the commitment to conserving the state's rich natural heritage, a stronger and more coordinated effort is needed to help ease ecological transitions and ensure that human activity does not cause further harm.

Acknowledgments The authors thank the following individuals for discussing issues related to climate adaptation and conservation planning with us either in person or by telephone: Michael Beck, Vicki Campbell, Jim Dempsey, Holly Doremus, Rob Klinger, Robert Leiter, Amy Luers, Connie Millar, Reed Noss, Gail Presley, Steve Ritchie, Brad Samuelson, Rebecca Shaw, Dan Silver, Wayne Spencer, Gregory A. Thomas, and David Zippin. We also thank Ellen Hanak, Louise Bedsworth, Rebecca Shaw, Michael Teitz, and anonymous reviewers for helpful comments, Lynette Ubois for editorial guidance, and Sarah Swanbeck for her assistance with figures. This research was supported by the Public Policy Institute of California, The Nature Conservancy, Next Ten Foundation, and Pacific Gas and Electric Company.

References

Ackerly DD, Loarie SR, Cornwell WK, Weiss SB, Hamilton H, Branciforte R, Kraft NJB (2010) The geography of climate change: implications for conservation biogeography. Divers Distrib 16:476–487

Barnett TP, Pierce DW, Hidalgo HG, Bonfils C, Santer BD, Das T, Bala G, Wood AW, Nozawa T, Mirin AA, Cayan DR, Dettinger MD (2008) Human-induced changes in the hydrology of the Western United States. Science 319:1080. doi:1010.1126/science.1152538

Barrows ME (2007) The natural communities conservation planning act: an assessment of its efficiency in preserving biodiversity. Dissertation, University of California, Irvine

Beever EA, Brussard PF, Berger J (2003) Patterns of apparent extirpation among isolated populations of pikas (Ochotona princeps) in the Great Basin. J Mammal 84:37–54

Bennett WA (2005) Critical assessment of the delta smelt population in the San Francisco Estuary, California. San Franc Estuary Watershed Sci 3:Art. 1

Bonfils C, Duffy PB, Santer BD, Wigley TML, Lobell DB, Phillips TJ, Doutriaux C (2007) Identification of external influences on temperatures in California. Clim Chang. doi:10.1007/s10584-007-9374-9

Bradley BA, Wilcove DS (2009) When invasive plants disappear: transformative restoration possiblities in the Western United States resulting from climate change. Restor Ecol 17:715–721

Bunn D, Mummert A, Hoshovsky M, Gilardi K, Shanks S (2007) California wildlife: conservation challenges (California's wildlife action plan). UC Davis Wildlife Health Center for California Department of Fish and Game, Sacramento

California Air Resources Board (2007) Staff report: proposed adoption of California climate action registry forestry greenhouse gas protocols for voluntary purposes. California Air Resources Board, Sacramento

California Continuing Resources Investment Strategy Project (2001) First draft report on the methodology to identify state conservation priorities. California Resources Agency, Sacramento

California Department of Fish and Game (2009) Lands inventory fact sheet. California Department of Fish and Game. As of December 7

California Department of Fish and Game (2010) Conservation and mitigation banks in California approved by the Department of Fish and Game. California Department of Fish and Game

California Fish and Game Commission (April 7, 2010) Notice of findings

California Natural Resources Agency (2009) 2009 California climate adaptation strategy: a report to the governor of the state of California in response to executive order S-13-2008. California Natural Resources Agency, Sacramento, p 200

California Senate Office of Research (2002) Timber harvesting and water quality: forest practice rules fail to adequately address water quality and endangered species. Sacramento, California

Camacho AE (2007) Can regulation evolve? Lessons from a study in maladaptive management. UCLA Law Rev 55:293–358

Camacho AE (2009) Adapting governance to climate change: managing uncertainty through a learning infrastructure. Emory Law J 59:1–78

Cayan DR, Kammerdiener SA, Dettinger MD, Caprio JM, Peterson DH (2001) Changes in the onset of spring in the Western United States. Bull Am Meteorol Soc 82:399–415

Cayan D, Maurer EP, Dettinger MD, Tyree M, Hayhoe K (2008) Climate change scenarios for the California region. Clim Chang 87:S21–S42

Christensen NL, Bartuska AM, Brown JH, Carpenter S, D'Antonio C, Francis R, Franklin JF, MacMahon JA, Noss RF, Parsons DJ, Peterson CH, Turner MG, Woodmansee RG (1996) The report of the Ecological Society of America Committee on the Scientific Basis for Ecosystem Management. Ecol Appl 6:665–691

Climate Action Team Economic Subgroup (2007) Climate strategy updates, prepared for updated macroeconomic analysis of climate strategies presented in the March 2006 climate action team report, public review draft. Sacramento, California

Craig RK (2010) 'Stationarity is dead'—long live transformation: five principles for climate change adaptation law. Harv Environ Law Rev 34:9–75
Cylinder P, Bogdan K, Zippin D (2004) Understanding the habitat conservation planning process in California: a guidebook for project and regional conservation planning. Institute for Local Self Government, Sacramento
Davis MB, Shaw RG (2001) Range shifts and adaptive responses to Quaternary climate change. Science 292:673–679
Doremus H (2001) Adaptive management, the Endangered Species Act, and the institutional challenges of 'new age' environmental protection. Washburn Law J 41:50–88
Dukes JS, Mooney HA (1999) Does global change increase the success of biological invaders? TREE 14:135–139
Elmqvist T, Folke C, Nyström M, Peterson G, Bengtsson J, Walker B, Norberg J (2003) Response diversity, ecosystem change, and resilience. Front Ecol Environ 1:488–494
Epps CW, McCullough DR, Wehausen JD, Bleich VC, Rechel JL (2004) Effects of climate change on population persistence of desert-dwelling mountain sheep in California. Conserv Biol 18:102–113
Fire and Resource Assessment Program (2003) The changing California: forest and range 2003 assessment. California Department of Forestry and Fire Protection, Sacramento
Gaffin JM (1997) Can we conserve California's threatened fisheries through natural community conservation planning? Environ Law 27:791–801
Gordon TM, Alderete JC, Murphy PJ, Sonstelie J, Zhang P (2007) Fiscal realities: budget tradeoffs in California government. Public Policy Institute of California, San Francisco
Greer KA (2004) Habitat conservation planning in San Diego county, California: lessons learned after 5 years of implementation. Environ Pract 6:230–239
Groves CR, Jensen DB, Valutis LL, Redford KH, Shaffer ML, Scott JM, Baumgartner JV, Higgins JV, Beck MW, Anderson MG (2002) Planning for biodiversity conservation: putting conservation science into practice. BioScience 52:499–512
Hannah L, Hansen L (2005) Designing landscapes and seascapes for change. In: Lovejoy TE, Hannah L (eds) Climate change and biodiversity. Yale University Press, New Haven, pp 329–341
Hannah L, Salm R (2005) Protected areas management in a changing. In: Lovejoy TE, Hannah L (eds) Climate climate change and biodiversity. Yale University Press, New Haven, pp 363–374
Hannah L, Midgley GF, Lovejoy TE, Bond WJ, Bush M, Lovett JC, Scott D, Woodward FI (2002) Conservation of biodiversity in a changing climate. Conserv Biol 16:264–268
Harris JA, Hobbs RJ, Higgs E, Aronson J (2006) Ecological restoration and global climate change. Restor Ecol 14:170–176
Hatch L, Uriarte M, Fink D, Aldrich-Wolfe L, Allen RG, Webb C, Zamudio K, Power A (2002) Jurisdiction over endangered species' habitat: the impacts of people and property on recovery planning. Ecol Appl 12:692–700
Hayhoe K, Cayan D, Field CB, Frumhoff PC, Maurer EP, Miller NL, Moser SC, Schneider SH, Cahill KN, Cleland EE, Dale L, Drapek R, Hanemann RM, Kalkstein LS, Lenihan J, Lunch CK, Neilson RP, Sheridan SC, Verville JH (2004) Emissions pathways, climate change, and impacts on California. Proc Natl Acad Sci USA 101:12422–12427
Heller NE, Zavaleta ES (2009) Biodiversity management in the face of climate change: a review of 22 years of recommendations. Biol Conserv 142:14–32
Hierl LA, Regan HM, Franklin J, Deutschman DH (2005) Assessment of the biological monitoring plan for San Diego's multiple species conservation program: report for task A of local assistance grant #P0450009. San Diego State University, for California Department of Fish and Game, San Diego, California
Hopkins J (2004) Regional conservation planning in California: a guide. Institute for Ecological Health, Davis
Hughes FMR, Colston A, Mountford JO (2005) Restoring riparian ecosystems: the challenge of accommodating variability and designing restoration trajectories. Ecol Soc 10:12
IPCC (2007) Summary for policymakers. In: Parry ML, Canziani OF, Palutikof JP, Linden PJvd, Hanson CE (eds) Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp 7–22
Kremen C, Williams NM, Thorp RW (2002) Crop pollination from native bees at risk from agricultural intensification. Proc Natl Acad Sci USA 99:16812–16816
Krist J (2006) Humboldt habitat conservation plan upheld, but logger loses water ruling. Calif Plann Dev Rep 21
Krist J (2007) Court ruling offers warning to habitat plan negotiators. Calif Plann Dev Rep 22
Kueppers LM, Snyder MA, Sloan LC, Zavaleta ES, Fulfrost B (2005) Modeled regional climate change and California endemic oak ranges. Proc Natl Acad Sci USA 102:16281–16286

Landis JD, Pendall R, Olshansky R, Huang W (1995) Fixing CEQA: options and opportunities for reforming the California environmental quality act. California Policy Seminar. University of California Berkeley, California

Lawler JJ, Tear TH, Pyke CR, Shaw MR, Gonzalez P, Kareiva P, Hansen L, Hannah L, Klausmeyer K, Aldous A, Bienz C, Pearsall S (2010) Resource management in a changing and uncertain climate. Front Ecol Environ 8:35–43

Legislative Analyst's Office (2003a) Environmental protection indicators. Analysis of the 2003–04 Budget Bill, Sacramento, California

Legislative Analyst's Office (2003b) Resource assessments: improving effectiveness and creating savings. Analysis of the 2003–04 Budget Bill, Sacramento, California

Legislative Analyst's Office (2007) Improving the appraisal function in resources land acquisitions. Sacramento, California

Legislative Analyst's Office (2008) 2008–09 Budget overview: resources agency departments. Sacramento, California

Legislative Analyst's Office (2010) The 2010–11 budget: resources and environmental protection. Sacramento

Little Hoover Commission (1994) Timber harvest plans: a flawed effort to balance economic and environmental needs. Sacramento, California

Loarie SR, Carter BE, Hayhoe K, McMahon S, Moe R, Knight CA, Ackerly DD (2008) Climate change and the future of California's endemic flora. PLoS ONE 3:e2502. doi:2510.1371/journal.pone.0002502

Macmynowski DP, Root TL, Ballard G, Geupel GR (2007) Changes in spring arrival of nearctic-neotropical migrants attributed to multiscalar climate. Glob Change Biol 13:2239–2251

Malcolm JR, Liu C, Neilson RP, Hansen L, Hannah L (2006) Global warming and extinctions of endemic species from biodiversity hotspots. Conserv Biol 20:538–548

Manthripragada, D (2006) Species protection versus state agency autonomy: striking the appropriate balance under the California Endangered Species Act. UCLA/Frankel Working Paper #3. The Evan Frankel Environmental Law and Policy Program. UCLA School of Law

Maurer EP, Brekke L, Pruitt T, Duffy PB (2007) Fine-resolution climate projections enhance regional climate change impact studies. Eos 88:504

McCarty JP (2001) Ecological consequences of recent climate change. Conserv Biol 15:320–331

McLaughlin JF, Hellmann JJ, Boggs CL, Ehrlich PR (2002) Climate change hastens population extinctions. Proc Natl Acad Sci USA 99:6070–6074

Millar CI, Westfall RD (2010) Distribution and climatic relationships of the American pika (Ochotona princeps) in the Sierra Nevada and Western Great Basin, U.S.A.; Periglacial landforms as refugia in warming climates. Arct Antarct Alp Res 42:76–88

Millar CI, Stephenson NL, Stephens SL (2007) Climate change and forests of the future: managing in the face of uncertainty. Ecol Appl 17:2145–2151

Moritz C, Patton JL, Conroy CJ, Parra JL, White GC, Beissinger SR (2008) Impact of a century of climate change on small-mammal communities in Yosemite National Park, USA. Science 322:261–264

Myers N, Mittermeier RA, Mittermeier CG, Fonseca GABd, Kent J (2000) Biodiversity hotspots for conservation priorities. Nature 403:853–858

Nagle JC, Ruhl JB (2002) The law of biodiversity and ecosystem management. Foundation Press, New York

Natural Resources Defense Council et al. v. Dirk Kempthorne, in his official capacty as Secretary of the Interior, et al. (2007) Case 1:05-cv-01207-OWW-NEW, E.D. California

Office of Environmental Health Hazard Assessment (2004) Environmental protection Indicators for California. California Environmental Protection Agency, with Department of Health Services, California Resources Agency, Sacramento, California

Opperman JJ, Bernazzani P (2003) Comparing perspectives of participants and outside commentators on habitat conservation plans. Endanger Species Update 20:79–90

Pacific Coast Federation of Fishermen's Associations, Institute for Fisheries Resources, et al. v. Carlos M. Gutierrez, in his official capacity as Secretary of Commerce, et al. (2008) Case 1:06-cv-00245-OWW-GSA, E.D. California

Pelini SL, Dzurisin JDK, Prior K, Williams CM, Marsico TD, Sinclair BJ, Hellmann JJ (2009) Translocation experiments with butterflies reveal ilmits to enhancement of poleward populations under climate change. Proc Natl Acad Sci USA. doi:10.1073/pnas.0900284106

Pollak D (2001a) Natural Communities Conservation Planning (NCCP): the origins of an ambitious experiment to protect ecosystems. California Research Bureau, Sacramento

Pollak D (2001b) The future of habitat conservation? The NCCP Experience in Southern California. California Research Bureau, Sacramento

Rahn ME, Doremus H, Diffendorfer J (2006) Species coverage in multispecies habitat conservation plans: where's the science? BioScience 56:613–619

Ruhl JB (2005) Regulation by adaptive management—is it possible? Minn J Law Sci Tech 7

Ruhl JB (2008) Climate change and the endangered species act: building bridges to the no-analog future. Boston Univ Law Rev 88

Ruhl JB (2009) Keeping the endangered species act relevant. Duke Environ Law Pol Forum 19:275–293

Sagarin RD, Barry JP, Gilman SE, Baxter CH (1999) Climate-related change in an intertidal community over short and long time scales. Ecol Monogr 69:465–490

San Diego Association of Governments (2006) 2007 Comprehensive regional transportation plan white paper: environmental mitigation program, minutes of the joint meeting of the regional planning and transportation committees. San Diego Association of Governments, San Diego

Spencer WD, Beier P, Penrod K, Winters K, Paulman C, Rustigian-Romsos H, Strittholt J, Parisi M, Pettler A (2010) California essential habitat connectivity project: a strategy for conserving a connected California. California Department of Transportation, California Department of Fish and Game, and Federal Highways Administration

Stachowicz JJ, Terwin JR, Whitlach RB, Osman RW (2002) Linking climate change and biological invasions: ocean warming facilitates nonindigenous species invasions. Proc Natl Acad Sci USA 99:15497–15500

Stein BA (2002) States of the union: ranking America's biodiversity. NatureServe, Arlington

Stein BA, Kutner LS, Hammerson GA, Master LL, Morse LE (2000) State of the states: geographic patterns of diversity, rarity, and endemism. In: Stein BA, Kutner LS, Adams JS (eds) Precious heritage: the status of biodiversity in the United States. Oxford University Press, New York, pp 119–157

Thomas GA (2000) Where property rights and biodiversity converge: lessons from experience in habitat conservation planning. Natural Heritage Institute, San Francisco

U.S. Fish and Wildlife Service (2010a) Conservation plans and agreements database, region 8. As of June 2, 2010

U.S. Fish and Wildlife Service (2010b) Endangered and threatened wildlife and plants; 12-month finding on a petition to list the American pika as threatened or endangered; proposed rule, 50 CFR Part 17. Fed Regist 75(26):6438–6471

van Mantgem PJ, Stephenson NL (2007) Apparent climatically induced increase of tree mortality rates in a temperate forest. Ecol Lett 10:909–916

van Rheenen NT, Wood AW, Palmer RN, Lettenmaier DP (2004) Potential implications of PCM climate change scenarios for Sacramento—San Joaquin River Basin hydrology and water resources. Clim Chang 62:257–281

Vasey MC, Holl KD (2007) Ecological restoration in California: challenges and prospects. Madrono 54:215–224

Visser ME, Holleman LJM (2001) Warmer springs disrupt the synchrony of oak and winter moth phenology. Proc R Soc B 268:289–294

Wayburn LE, Franklin JF, Gordon JC, Binkley CS, Mladenoff DJ, Christensen NL, Jr. (2007) Forest carbon in the United States: opportunities & options for private lands. Pacific Forest Trust

Westerling AL, Hidalgo HG, Cayan D, Swetnam TW (2006) Warming and earlier spring increase Western U. S. forest wildfire activity. Science 313:940–943

Wheeler DP, Rowberry RM (2009) Habitat conservation plans and the endangered species act. In: Bauer DC, Irvin WR (eds) Endangered species act: law, policy, and persepectives, 2nd edn. American Bar Association, Chicago, pp 220–240

Wilcove DS, Rothstein D, Dubow J, Phillips A, Losos E (2000) Leading threats to biodiversity: what's imperiling U.S. species. In: Stein BA, Kutner LS, Adams JS (eds) Precious heritage: the status of biodiversity in the United States. Oxford University Press, New York, pp 239–254

Wilhere GF (2002) Adaptive management in habitat conservation plans. Conserv Biol 16

Zavaleta ES, Hulvey KB (2004) Realistic species losses disproportionately reduce grassland resistance to biological invaders. Science 306:1175–1177