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Conservation and Management of Ecological Systems in a Changing California

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with research support from Sarah Swanbeck

Supported with funding from Next Ten, Pacific Gas and Electric Company, and The Nature Conservancy

This report is part of a larger PPIC study, *Preparing California for a Changing Climate.* Other reports in this collection are available at http://www.ppic.org/main/publication.asp?i=755.

November 2008

Contents

Summary

Protecting California's unique 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 (plants and animals occurring nowhere else on Earth). Habitat loss, deterioration, and fragmentation have combined with pressures from invasive species to put more than 35 percent of the state's plants and nearly 14 percent of California's wildlife at risk of extinction. Climate change introduces additional, uncertain risks to California's ecosystems and species, ranging from changes in the timing of bird migrations, to large-scale redistribution of species on the landscape, to increases in forest fires. In addition, climate change will interact with other stressors already threatening species and ecosystems, making it more difficult to achieve management and conservation goals.

A multitude of federal and state agencies share responsibility for land, water and coastal resource management. 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). Reflecting its status as a biodiversity hotspot, California has been a national leader in leveraging the ESA and CESA to develop proactive, bioregional conservation plans in order to avoid conflicts between environmental and economic goals. In particular, California enacted the Natural Communities Conservation Planning Act (NCCP) to promote development of large, continuous reserves for multiple species. These more forward-looking programs will aid the state in addressing planning challenges related to climate change. However, in fundamental ways, the existing planning and regulatory system for protecting biodiversity remains ill-equipped for meeting the challenge. In particular, the basic regulatory tools for protecting species health are often implemented in a reactive and piecemeal fashion, and coordination is lacking across government jurisdictions and policy domains such as water quality and forest management.

Reorienting the planning and regulatory system to become more adaptive will be a major challenge. Principles already advocated for sound reserve design may provide some basis. However, stepped-up reserve acquisition, even if it relies on robust design principles, will still require a process to prioritize investments. To enable species persistence, managers will need to develop assessment indicators and assistance strategies that are not dependent on current habitat structure or distribution. As climate change alters the natural landscape, species decline cannot be framed mainly as a local problem amenable to solutions in one given place.

A new, much stronger and more coordinated conservation planning effort is required from the state government if California is to honor the commitment to species enshrined in laws and programs such as CESA and the NCCP. Although ESA and CESA remain safeguards against extinction, their reactive stance may prove counter-productive in developing the most promising strategies for supporting ecosystem and species health overall. Forward-looking programs such as the NCCP must be re-organized within a larger state framework that identifies and protects "missing" habitat linkages needed for species migration, and that supports transition strategies for individual species across jurisdictional boundaries. A more coordinated framework can also facilitate integrated planning of habitat conservation with other objectives, such as providing infrastructure, developing land in metropolitan areas, and mitigating (limiting) climate change.

Acknowledgments

The authors wish to thank the individuals listed in the appendix at the end of the report who generously agreed to discuss issues related to climate adaptation and conservation planning with us through in-person meetings and telephone conversations during the course of our research. We thank Rebecca Shaw and Michael Teitz for helpful comments on an earlier draft, and Lynette Ubois for editorial guidance. We also thank Sarah Swanbeck for her assistance in developing the maps for this report.

Acronyms

CESA	California Endangered Species Act
CEQA	California Environmental Quality Act
DFG	California Department of Fish and Game
EPIC	Environmental Protection Indicators for California
ESA	Endangered Species Act
FWS	U.S. Fish and Wildlife Service
HCP	habitat conservation plan
LAO	Legislative Analyst's Office
NCCP	Natural Communities Conservation Planning Act
RCP	Regional Comprehensive Plan
SAMP	Special Area Management Plan
SANDAG	San Diego Association of Governments

Introduction

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 unique 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 natural communities as we know them, 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 management and conservation goals.

The laws and policies already in place to promote conservation efforts embody our state's commitment to other species: that we will not allow our achievements to come at the expense of their very survival. Reflecting its status as a biodiversity hotspot, 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 approaches to conservation strategies, such as habitat protection, will not be adequate for protecting species and ecosystems. The current policy structure for conserving species must be adapted to this widely recognized threat or we will, in effect, be abdicating our original commitment.

Even as climate change presents a daunting challenge for efforts to manage and protect the state's rich natural heritage, it also presents certain opportunities. In many 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. 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 with ecosystem conservation and restoration.

In this report, we address conservation and resource management challenges for protecting biodiversity in the face of climate change, focusing, in particular, on land-based conservation of natural habitat near developing urban areas and in more remote forested areas. Throughout the report, we use "adaptation" to mean the decisions and actions taken by humans to modify our current practices with the aim of enabling species and ecosystems to successfully respond to the changing climate.

We first highlight the conservation challenge in California and the special risks to species and ecosystems that are posed by human-induced climate change. We then review the primary laws and regulatory processes that are currently used to prevent species extinction and conserve habitat. Next, we discuss challenges and opportunities to adapting the current policy structure to the realities of climate change. That is, we try to answer the question, what should programs designed to aid species and ecosystem conservation look like in the face of climate change? We follow this discussion by highlighting shortcomings in our existing policy structure and finally make some recommendations for changes needed to adapt policies and institutions to the realities facing species and natural resources more generally.

1. **Current Threats to Native Species and Ecosystems**

Protecting California's unique 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 et al., 2002; Stein et al., 2000). Habitat loss, deterioration, and fragmentation resulting from dams and water diversions, urban growth, agricultural expansion, and forestry activities have combined with pressures from invasive species to put more than 30 percent of the state's flora (nearly 1,700 species) and over 15 percent of California's vertebrate wildlife (125 species) at risk of extinction (Stein et al., 2002; Stein et al., 2000). Yet less than one-fifth of California land is in public reserves managed for biodiversity values, nearly all of which is in mountainous or desert regions. About 64 percent 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 percent 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 percent of their historic size and with only 20 percent 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, what habitat is left is significantly fragmented, with populations of endemic or rare species increasingly isolated from one another. Urban development has consumed 40 percent of the land area, reducing vernal pool habitat by 95 percent and coastal sage scrub by 82 percent (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.

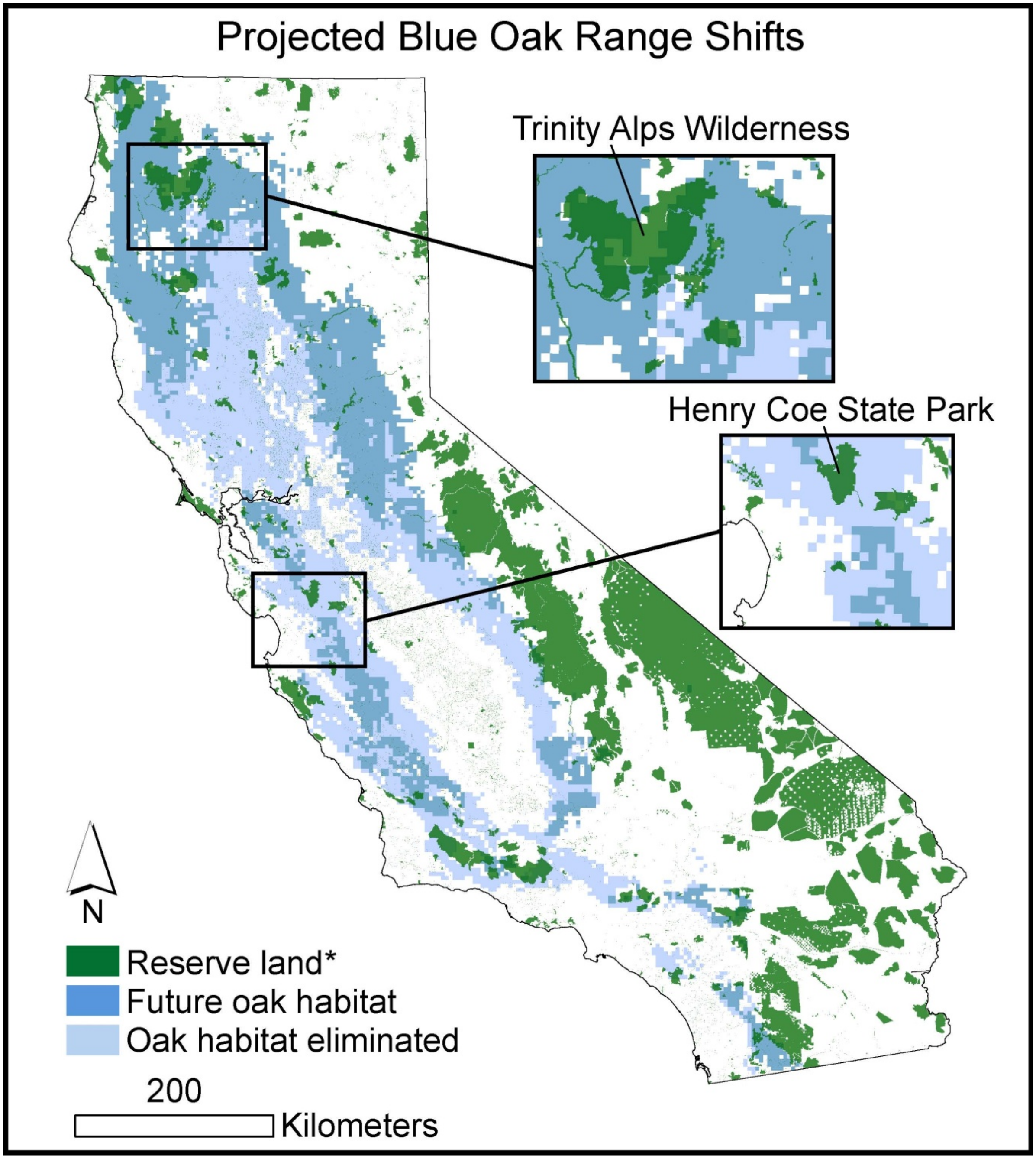
Other ecosystems in the state have experienced significant disruption from invasive species and past timber harvest or grazing (Bunn et al., 2007). Current old growth forest is about one quarter of its historic extent (FRAP, 2003). During the 1990s and early 2000s, forestland in the state was converted 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.

2. 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 in California, while other changes 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 percent of those assessed so far) if global temperatures exceed 2.7 to 4.5 ºF (1.5 to 2.5ºC) above the historic average (Intergovernmental Panel on Climate Change, 2007). In turn, this threat will be compounded by other ongoing challenges to species survival.

Climate change is already underway in California. 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) 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).

The climate-induced risks of large-scale changes in the geographic distributions of species and of increases in species extinctions challenge the notion that habitat protection alone will ensure the future of many species, particularly endemic species. 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; Figure 1). At the same time, other reserves, such as Trinity Alps Wilderness may be newly suited to blue oak but unsuited to other current species (Figure 1).



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 management objective.

Figure 1. Projected Blue Oak Range Shifts

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 percent, with anywhere from 2 to 46 percent 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 significant biodiversity losses (Loarie et al. 2008).

Anticipated ecological changes with continued climate change are contingent on the 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 where 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' seeds are large and not transported very far), or could be due to barriers such as mountain ranges or large expanses of inhospitable urban and agricultural land. 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' ranges shift, 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 (Visser et al., 2001). 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) (McLaughlin et al., 2002, Epps et al., 2004). 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 Rheenan 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 favored by disturbed environments (Wilcove et al., 2000). Recent work in grasslands suggests that invasive species are more successful when ecosystems have lost important native

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[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.

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). 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, the risks from climate change to California's native biodiversity are large and multifaceted. Adapting our efforts to protect species and ecosystems to this new reality is a critical challenge.

3. The Regulatory Framework for Conservation and Resource Management

A multitude of federal and state agencies share responsibility for land, water and coastal resource management in California. As in much of the country, their conservation and management strategies must be integrated with economic activity. The missions of both federal and state resource agencies reflect this reality, incorporating recreational and economic production goals as key objectives along with conservation of ecological values such as biodiversity and natural habitat.

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 regulatory system for protecting biodiversity remains ill-equipped for meeting the challenge. In particular, the basic regulatory tools for protecting species health 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).

Species Protection Laws and Programs

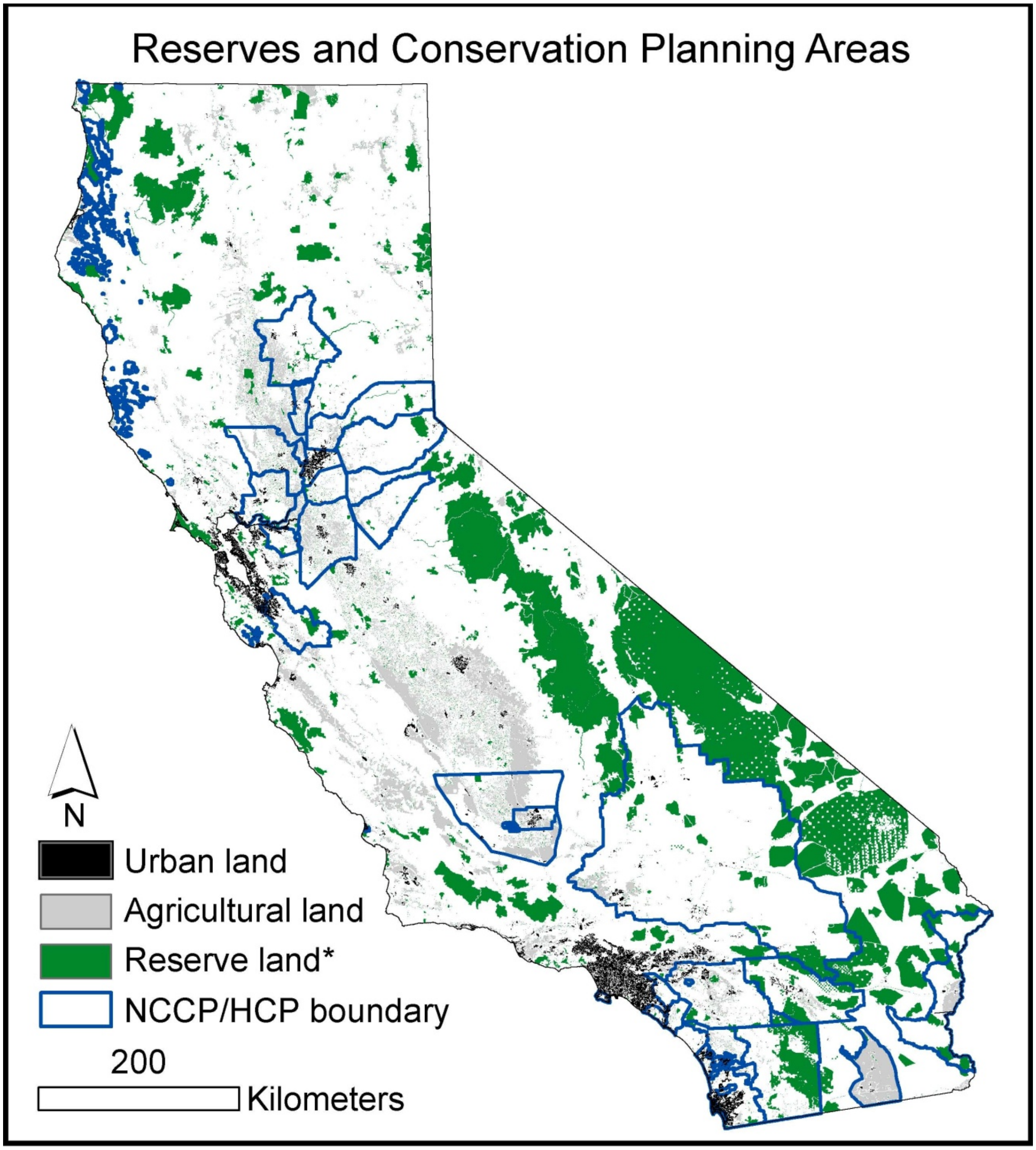
Within the larger framework of natural resource regulation, the primary laws for protecting species health on public and private lands are the federal Endangered Species Act (ESA), and its state equivalent, the California Endangered Species Act (CESA). ESA and CESA are considered tough environmental laws because of their stiff prohibitions against “take” of endangered plants and wildlife. “Take” means not just outright killing of listed organisms but also significant proximal degradation of habitat that results in death or injury. 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 also issue permits to landowners whose actions result in take, if the permittees mitigate their action by setting aside land or contribute in other ways to reserve land acquisition.

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 and 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).[2]

[2] In California, 125 HCPs have been approved (USFWS, 2008). Many cover a single species for a short term (five to ten years), but many are large-scale, multi-species “regional” HCPs.

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 and b). 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. The plans can cover more than 100 species and extend as many as 75 years.[3] The acreage included in the NCCP and regional HCP plan areas in California comprised more than 25 percent of the total state land and water area in the state.

[3] NCCP plans are developed cooperatively by federal and state agencies, local governments, and private sector and non-profit stakeholders. There are 32 active, in-progress NCCPs (many of them HCPs as well) covering more than seven million acres; 12 have been approved and permitted (California Department of Fish and Game NCCP website, as of October 24, 2008).



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.

Figure 2 Reserve and Conservation Planning Areas in California

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, such as in the Bay-Delta region, the Colorado River, and the Salton Sea.

Water-Related Laws and Programs

Certain water-related laws and programs also protect wildlife, 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 some 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).[4] 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.[5]

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 percent 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 decisionmakers for conservation.

However, without regional processes to provide a framework for local action, local governments' attention to conservation has been variable and sometimes inadequate (Hopkins, 2004; Bunn et al., 2007). 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 formed a weak impetus for local conservation

[4] DFG has approved 38 conservation mitigation "banks" statewide, allowing for tradeable offset credits, most for wetlands projects. DFG also oversees various incentive programs to promote conservation on private lands; about 44 percent of DFG-administered land is managed through easements, leases or other agreements with landowners (DFG, n.d.).

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activity.[6] It works better when coupled with policy standards and objectives that can be translated into practical regulatory steps locally—such as through NCCPs (Landis et al., 1995).

Effective coordination would link various regional plans, such as NCCPs, watershed management plans, transportation, and energy plans. 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 with regional plans for transportation, land use, water, energy, and other elements. A ballot measure, called TransNet, was approved by county voters in 2004 to extend a half-cent county sales tax increase for transportation improvements linked to the RCP. TransNet includes $650 million (over its 40-year duration) for transportation-related habitat mitigation, and $200 million for NCCP acquisition, management, and monitoring (SANDAG, 2006).

The San Diego plan is one of the most advanced of the so-called "regional blueprint" plans currently being developed by regional transportation planning agencies across the state (Barbour and Teitz, 2006). The blueprint process coordinates long-range plans for transportation investment, air quality, and land use at the regional and local levels. The process relies on scenario modeling of likely growth-related outcomes, such as for housing location, transportation mobility, and environmental quality, as well as a public outreach process to local governments and neighborhood residents. The goal is to identify and implement preferred development scenarios.

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). Lack of interjurisdictional coordination also has weakened implementation of the NCCP plan's adaptive management and monitoring program (Greer, 2004; Hierl et al., 2005). In general, conflicting mandates and interjurisdictional coordination problems among public agencies pose some of the worst challenges facing conservation planners (Doremus, 2001; Hatch et al., 2002).

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).

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[6] 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 (Hopkins, 2004; Bunn et al., 2007).

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 (FRAP, 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 in particular regarding impacts of timber harvesting on watershed health and at-risk fish species (California Senate Office of Research, 2002; FRAP, 2003).

The State Government's Role

Although the State of California owns only 3 percent 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 spent 80 percent more on natural resource programs in 2002 than the average for all other states (Gordon et al., 2007). However, California's spending was lower than in other western states or Florida, which face similar water management issues. California also spent less in real terms during the 1990s and early 2000s than in previous decades, in spite of passing several bond measures.

From 2000 to mid-2007, the state government spent over $2 billion for land acquisition and easements, mostly from resources bonds (LAO, 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 (LAO, 2008).

Although the bond funds will aid conservation, the state lacks a clear policy framework for guiding expenditures or determining whether they are sufficient (Bunn et al., 2007; LAO 2003a). A multi-stakeholder effort called the Legacy Project was launched in the early 2000s to develop state conservation priorities, but it ran aground (LAO, 2003b). Furthermore, ongoing program activities of DFG receive a small portion of the total state resources budget; state general fund support for this department dropped from $84 million in 2000 to $37 million in 2005 (Bunn et al., 2007).[7] With natural resources under greater pressure from climate change, more dependable state funding is needed, but also more clarity regarding how to target funds.

[7] 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).

4. Challenges and Opportunities for Adaptation

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. Meanwhile, the uncertainty posed by climate change for ecosystem and species health will make coordinating conservation planning more difficult. Still, certain basic principles hold promise going forward: (i) following sound basic principles for reserve design, (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.

The Challenge for Habitat Planning Posed by Climate Change

Climate change poses formidable challenges for conservation planners. 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 we know them will reconfigure, with higher risks to some species than to others. To address current and future needs of species and to avoid intensifying conflicts between environmental and economic uses of natural resources, a greater level of coordination will be needed than ever before across jurisdictions, agencies, and policy areas.

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 endangered species 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). An example is the rabbit-like pika which inhabits mountain-top "islands" of the Sierra Nevada mountains. This species will likely face extinction because of temperature effects of climate change (Ruhl, 2008). Meanwhile, some species may actually thrive as a result of climate change, even posing a threat to native species they encounter as they expand their ranges. Some species not yet in severe decline may depend on proactive strategies to maintain habitat or ease transition 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 agencies 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, output from models that "downscale" projected global climate change to local levels is only beginning to become available, and models do not yet address the complex interplay of local economic and environmental pressures on species and ecosystems of concern (Ruhl, 2008). 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 may 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 drive the need for more coordinated solutions. 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.

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.

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.

Adaptation of Conservation Planning

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 (Intergovernmental Panel on Climate Change, 2007; McCarty, 2001).

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 conservation strategies addressing species' needs individually (Christensen et al., 1996; Groves et al., 2002). In the face of climate change, large-scale reserve systems encompassing landscape gradients (e.g., low-high elevation) and north-south corridors may aid transitions and provide some insurance for species movement. Thus, basic design principles for adaptive strategies include strengthening fixed elements (reserves) as well as connectivity among reserves, and limiting external pressures that will act synergistically with climate change, such as pollution (Hannah and Hansen, 2005).

Even if it relies on robust design principles, stepped-up reserve acquisition will still also require a process to prioritize investments. 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 anticipate impacts of climate change and that are responsive to changing biophysical conditions (Hannah et al., 2002; Harris et al., 2006). Accomplishing this task will require a greater commitment to science-based "adaptive management," including ongoing experimentation and re-evaluation of management strategies in light of experimental results. Scientists also will need to engage at all levels in the often messy and incremental political processes by which state and regional conservation strategies are developed (Christensen et al., 1996).

To enable species persistence, managers will need to develop assessment indicators and assistance strategies that do not depend on current habitat structure or distribution. This might involve using non-local genetic material in restoration, for example (Harris et al., 2006). 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. 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).

For instance, 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, to reduce pressures from invasive species and human fire ignitions.

Adaptation of Resource Management

Adaptive management strategies will also be important to address climate change in the natural resource management context.. To avoid catastrophic conversions of forest ecosystems, concerted efforts are needed 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 at a given point in time (Millar et al., 2007).

Millar and colleagues have identified three general approaches for forest managers to consider: (1) create resistance to change, (2) promote resilience to change, and (3) enable forests to respond to change. The first two of these are short–term options; ultimately, forests and grazing lands will respond to climate change, and managers will have to decide how to facilitate the transition. Tools might include actively assisting transitions in species' ranges (for instance, through "assisted migration"), enhancing redundancy in the face of uncertain outcomes (for instance, planting in multiple environments), relaxing restrictions on use of non-local genetic material, 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). Natural resource managers, like conservation planners, should seek to maintain or increase the connectedness of the landscape, and consider the future in restoration efforts.

Achieving Co-Benefits and Linking Mitigation with Adaptation

Climate change presents a daunting challenge for conservation planners. However, at the same time, it also presents certain opportunities. In many 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 in aligning 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 growth-related outcomes such as availability and demand for land, water, and energy. Such comprehensive modeling is currently being used in state water planning, reflecting the intense pressure on water resources. Comprehensive scenario modeling is also being employed by regional "blueprint" planners and 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 integrated planning tools in California are hampered by lack of clear jurisdictional authority over floodplains and groundwater (Bunn et al., 2007).

Achieving Co-Benefits in the Forestry Sector: Carbon Sequestration

In forestry management, strategies to promote carbon retention and uptake present another opportunity for combining mitigation (limitation) of climate change with adaptation (Wayburn et al., 2007, Millar et al., 2007). Such strategies include promoting markets for so-called "carbon sequestration" through reforestation, afforestation (developing new forested areas), and forest management for conservation. The win-win opportunity presented by a market for carbon could make larger scale protection of intact ecosystems viable in some locations and help prevent fragmentation and other pressures that can hinder 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.[8] 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 "naturally" for diversity and complexity at a landscape scale improves their resilience while providing co-benefits for habitats, biodiversity, and watershed function (Wayburn et al., 2007). Such policies need to be supported 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 (Wayburn et al., 2007; California Air Resources Board, 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 risk 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).

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[8] See http://www.climateregistry.org/PROTOCOLS/FP/. The forestry protocols require that carbon reductions are 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.

5. Is the State's Governance Framework Prepared?

California has made advances that will help conservation and resource management adapt to climate change. Climate impact assessments have begun to highlight challenges for ecological systems and their management, in particular, through work funded by the California Energy Commission's Public Interest Energy Research program. Certain state programs—notably the NCCP program—promote design principles and long-term "adaptive management" strategies that should aid in adaptation. However, there are few examples of on-the-ground management or conservation activities implemented to specifically address climate change impacts (Joyce and Laskowski 2006). 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.

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.

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.

In the face of risk and rapid change, ESA's and CESA's permitting provisions may hamper efforts to target resources where they might be most effective. The provisions may lead to difficult trade-offs between species, for example, if efforts to aid a listed species through assisted migration 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.

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, such as the pika, 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 (ibid).

Strengths and Limitations of NCCP's for Addressing Climate Change

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 the more proactive 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.[9] 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. For example, the plans impose a recovery standard for covered species (higher than for ESA or CESA take mitigation), which introduces the opportunity for considering climate change in acquisition and restoration efforts.

Scientific advisors have recommended including climate change in NCCP plans as a foreseeable "changed" circumstance, making climate-induced effects on species subject to remediation through stipulated measures (see, for example, Spencer et al., 2006). However, to date, no approved NCCP has done so. Furthermore, NCCPs and HCPs have been criticized for inadequate scientific oversight, adaptive management, and monitoring (Pollak, 2001a and b; Opperman and Bernazzani, 2003; Rahn et al., 2006). For example, the San Diego NCCP—the state's oldest plan, approved in 1996—is reorganizing management and monitoring in response to such criticism, including from the California courts (Greer, 2004; Hierl et al., 2005; Krist, 2007).

The problems with San Diego's NCCP reflect a set of obstacles impeding NCCPs more generally: lack of interjurisdictional coordination and inadequate ongoing funding (Greer, 2004; Cylinder et al., 2004; Ruhl, 2005; Hierl et al., 2005; Krist, 2007). These obstacles could seriously impede effective adaptation planning. In particular, as species migrate in response to climate change, interjurisdictional coordination will be critical for adaptation strategies to work. On the bright side, some promising coordination efforts have emerged, such as through the South Coast Missing Linkages Project (www.scwildlands.org). This project identified fifteen priority areas linking existing reserves, and then encouraged NCCP planners to adopt supportive policies.

Another challenge for NCCPs relates to the plans' 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 an actual

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[9] 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).

connection between individual species and ecosystem health in a given place. This premise will be challenged by climate change if current natural communities 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 regulatory mandate: to ease transitions for individual, covered 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 those environments.

To address such conflicts and concerns, managers will need to develop strategies for monitoring and assisting species not dependent on current habitat, and for habitat quality not dependent on current species groups.[10] Alternately, NCCP plans may need to be scaled back in terms of the number of species covered and/or their duration to enable more frequent evaluation of goals and progress.

An initiative that may hold promise for developing systematic indicators of ecosystem health independent of current habitat structure or distribution is the state 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 effects such as air temperature and sea level rise) and ecosystems 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 (LAO, 2003a). However, many EPIC indicators are still under development or not monitored systematically across the state. The project has brought to light significant data gaps for many environmental attributes (ibid).

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 interjurisdictional coordination problems that have plagued 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 incorporate NCCP objectives. The state government plays a decisive role in determining whether such coordinated planning is undertaken across programs and agencies.

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[10] Forest management plans will face similar challenges, as they often rely on similar "rule of thumb" methods for adaptive management of species and ecosystems (Nagle and Ruhl, 2002).

6. 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. A diversity of flexible approaches will be useful, 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 across time and across all parts of the state, stronger leadership from the state government will be needed.

A State Policy Framework

A state policy and program framework is needed to coordinate conservation in the face of climate change. Such a framework will need to address priorities for reserve land acquisition, research and management needs, and 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 all species by human-induced climate change. What could California do, on its own, to save the pika?

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 to drive conservation efforts by default, regardless of the costs, conflicts, and species' responses to human-induced climate change. But if prevention of extinction is not possible for all 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?

To begin to make these decisions, a state agency-stakeholder process might be initiated to develop policy and program proposals. Given the difficulties the Legacy Project encountered in trying to develop state conservation priorities, a more focused perspective would be prudent—perhaps one specifically oriented to developing climate change adaptation strategies. Attention should first 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?

The next step in developing a more coordinated approach to adaptation would be to define *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. 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: (1) places are singled out for protection that will retain or acquire value as habitat for resilient natural communities and self-sustaining ecosystems, and (2) transition strategies receive support to aid species requiring action across jurisdictional borders.

In terms of immediate priorities, given the rapid rate of climate change (compared to our ability to keep pace in developing adaptation measures) it may be practical in the short term to prioritize reserve acquisition by relying on basic, robust design principles. From this perspective, the more large-scale preserves with environmental gradients and corridors, 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 and ongoing adaptive management to identify priority reserve lands, and then continually seek to improve management and acquisition strategies in light of new knowledge.

Box: Elements of a State Policy Framework for Adaptive Conservation

- ❖ Clarify state goals for adaptive conservation policy.
  - What goals?
    - Save as many species as possible from extinction
    - Preserve "representativeness" of natural communities and species types
    - Ease species transitions as much as possible
  - In what order of priority?

- ❖ Clarify objectives for adaptive conservation policy
  - Integrate place-based and species-based strategies
  - Coordinate an integrated reserve system
  - Identify and protect areas that will retain or acquire value as habitat
  - Support transition strategies for species across jurisdictional borders
  - Boost reserve acquisition using robust design principles
  - Support scientific research and ongoing adaptive management

- ❖ Provide institutional and technical support for coordinated conservation planning
  - Establish a statewide "missing linkages" project
  - Align statewide habitat planning with other multi-sector efforts such as watershed management plans and metropolitan blueprints
  - Expand scientific assessment and scenario planning of climate-related impacts
  - Link scientists with on-the-ground managers and projects
  - Develop and implement indicators and monitoring strategies to assess ecosystem health not dependent on particular "indicator" species

Institutional Support for Adaptive Management

A stronger institutional framework is needed to carry out these objectives. In particular, this framework must coordinate local and regional conservation efforts. A statewide "missing linkages" project could be established to provide an overarching approach for identifying critical habitat needs that smaller-scale plans could fit into. This sort of program could help in identifying whether certain NCCP/HCP plans should be merged or coordinated, based on climate-induced transitions. It could help identify areas to target for acquisition or long-term management for environmental values, whether through NCCP/HCPs or other methods. It could align with other state and regional efforts to strengthen coordination, such as for integrated watershed management and regional land use blueprint development. Finally, it could help align public land management strategies for addressing climate change, such as between state and federal parks.

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 to adapting institutional frameworks and management practices. 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 projects' needs and help land managers develop future-oriented plans for aiding specific species' transitions. Another important task would be development of indicators and monitoring strategies to assess ecosystem health in a fashion not dependent on particular species. Such indicators might address diversity, functional redundancy, or other resilience measures (Groves et al., 2002).

As another form of institutional support, the state should strengthen coordinated planning to link mitigation with adaptation and to integrate planning across policy domains. For example, the state could strengthen technical and regulatory support for regional integrated watershed management planning and metropolitan blueprint planning. 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.

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. For example, climate change, and not simply its various impacts, could be considered a "changed" circumstance. Stepped-up requirements for periodic review by independent science advisors, and incentives that reward NCCP permit holders for long-term performance in relation to plan goals, could also make NCCP implementation more adaptive. Incentives might include requiring permit holders to post performance bonds as insurance for plan effectiveness and rewarding permit holders that provide reliable information benefiting a species, even if it means modifying management strategies as a result (Thomas, 2000). Finally, NCCP planners and managers should be encouraged to develop indicators, monitor, and manage for ecosystem health in a fashion not dependent on particular species. To ensure this occurs, 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.

To support development of strategies for aiding at-risk species, increased emphasis (and state funding) should be directed toward recovery planning and designation of "critical habitat." 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 given recovery plans. They might employ this discretion to target species predicted to be threatened by future development, or that have better chances of survival, or that are deemed critical functionally in reconfigured natural communities (Ruhl, 2008).

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 might raise necessary funds to acquire and manage habitat for ecosystem values in the face of climate change. 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 appropriate 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.

Conclusion

We stand at a painful transition point; ESA and CESA take prohibitions express our ethical commitment to preventing extinction of other species, but because of human-induced climate change, we likely have already condemned some species to extinction. Our 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.

But there is also no longer time to wait for more information. Climate change is underway in California, and our laws and institutions must adapt. In order to renew our commitment to conserving this state's rich natural heritage, a stronger and more concerted effort is needed to help ease ecological transitions and ensure that human activity does not cause further harm.

Appendix: People Interviewed for this Report

Vicki Campbell, Deputy Division Chief, Section 7, HC, EC & Forest Resources
U.S. Fish and Wildlife Service, California/Nevada Operations Office
Sacramento, California

Jim Dempsey, Environmental Scientist
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Oroville, California

Reed Noss, PhD., Davis-Shine Professor of Conservation Biology
Department of Biology, University of Central Florida
Orlando, Florida

Gail Presley, Program Manager
Conservation Planning Program, California Department of Fish and Game
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Gregory A. Thomas, President
Natural Heritage Institute
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Steve Ritchie, Executive Project Manager
South Bay Salt Ponds Restoration Project
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Holly Doremus, Professor of Law
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Rebecca Shaw, PhD., Director of Conservation Science and Planning
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Dan Silver, Executive Director
Endangered Habitats League
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David Zippin, PhD., Principal
Jones & Stokes
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References

Barbour, Elisa, and Michael Teitz, Blueprint Planning in California: Forging Consensus on Metropolitan Growth and Development, Public Policy Institute of California, San Francisco, California, 2006.

Bennett, W. A., "Critical Assessment of the Delta Smelt Population in the San Francisco Estuary, California." San Francisco Estuary and Watershed Science, Vol. 3, No. 2, Art. 1. 2005.

Bunn, D., A. Mummert, M. Hoshovsky, K. Gilardi, and S. Shanks, California Wildlife: Conservation Challenges (California's Wildlife Action Plan), UC Davis Wildlife Health Center for California Department of Fish and Game, Sacramento, California, 2007.

California Air Resources Board, Staff Report: Proposed Adoption of California Climate Action Registry Forestry Greenhouse Gas Protocols for Voluntary Purposes, Sacramento, California, October 17, 2007.

California Continuing Resources Investment Strategy Project, First Draft Report on the Methodology to Identify State Conservation Priorities, California Resources Agency, Sacramento, California, 2001.

California Department of Fish and Game, Lands Inventory Fact Sheet, no date, Sacramento, California, available at www.dfg.ca.gov/lands/factsheet.html

California Senate Office of Research, Timber Harvesting and Water Quality: Forest Practice Rules Fail to Adequately Address Water Quality and Endangered Species, Sacramento, California, 2002.

Cayan, D. R., S. A. Kammerdiener, M. D. Dettinger, J. M. Caprio, and D. H. Peterson, "Changes in the Onset of Spring in the Western United States," Bulletin of the American Meteorological Society, Vol. 82, No. 3, pp. 399-415, 2001.

Christensen, Norman L., Ann M. Bartuska, James H. Brown, Stephen Carpenter, Carla D'Antonio, Rober Francis, Jerry F. Franklin, James A. MacMahon, Reed F. Noss, David J. Parsons, Charles H. Peterson, Monica G. Turner, and Robert G. Woodmansee, "The Report of the Ecological Society of America Committee on the Scientific Basis for Ecosystem Management," Ecological Applications, Vol. 6, No. 3, pp. 665-691, 1996.

Climate Action Team Economic Subgroup, 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, September 4, 2007.

Cylinder, Paul, Kenneth Bogdan, and David Zippin, Understanding the Habitat Conservation Planning Process in California: A Guidebook for Project and Regional Conservation Planning, Institute for Local Self Government, Sacramento, California, 2004.

Davis, M. B., and R. G. Shaw, "Range Shifts and Adaptive Responses to Quaternary Climate Change," Science, Vol. 292, pp. 673-679, 2001.

Doremus, Holly, "Adaptive Management, the Endangered Species Act, and the Institutional Challenges of 'New Age' Environmental Protection," Washburn Law Journal Vol. 50, pp. 50-89, 2001.

Dukes, J. S., and H. A. Mooney, "Does Global Change Increase the Success of Biological Invaders?" Trends in Ecology and Evolution, Vol. 14, No. 4, pp. 135-139, 1999.

Epps, C. W., D. R. McCullough, J. D. Wehausen, V. C. Bleich, and J. L. Rechel, "Effects of Climate Change on Population Persistence of Desert-dwelling Mountain Sheep in California," Conservation Biology, Vol. 18, No. 1, pp. 102-113, 2004.

Fire and Resource Assessment Program, California Department of Forestry and Fire Protection, The Changing California: Forest and Range 2003 Assessment, Sacramento, California, 2003.

Gaffin, John M., "Can We Conserve California's Threatened Fisheries through Natural Community Conservation Planning?," Environmental Law, Vol. 27, No. 3, pp. 791-801, 1997.

Gordon, T.M., J.C. Alderete, P.J. Murphy, J. Sonstelie, P. Zhang, Fiscal Realities: Budget Tradeoffs in California Government, Public Policy Institute of California, San Francisco, California, 2007.

Greer, Keith A., "Habitat Conservation Planning in San Diego County, California: Lessons Learned after Five Years of Implementation," Environmental Practice, Vol. 6, No. 3, pp. 230-239, 2004.

Groves, Craig R., Deborah B. Jensen, Laura L. Valutis, Kent H. Redford, Mark L. Shaffer, J. Michael Scott, Jeffrey V. Baumgartner, Jonathan V. Higgins, Michael W. Beck, and Mark G. Anderson, "Planning for Biodiversity Conservation: Putting Conservation Science into Practice," BioScience, Vol. 52, No. 6, pp. 499-512, 2002.

Hannah, Lee, and Rod Salm, "Protected Areas Management in a Changing Climate," in Climate Change and Biodiversity, edited by Thomas E. Lovejoy and Lee Hannah, Yale University Press, New Haven, Connecticut, pp. 363-374, 2005.

Hannah, Lee, and Lara Hansen, "Designing Landscapes and Seascapes for Change," in Climate Change and Biodiversity, edited by Thomas E. Lovejoy and Lee Hannah, Yale University Press, New Haven, Connecticut, pp. 329-341, 2005.

Hannah, L., G. F. Midgley, T. Lovejoy, W. J. Bond, M. Bush, J. C. Lovett, D. Scott, and F. I. Woodward, "Conservation of Biodiversity in a Changing Climate," Conservation Biology, Vol. 16, No. 1, pp. 264-268, 2002.

Harris, J. A., R. J. Hobbs, E. Higgs, and J. Aronson, "Ecological Restoration and Global Climate Change," Restoration Ecology, Vol. 14, No. 2, pp. 170-176, 2006.

Hatch, Leila, Maria Uriarte, Daniel Fink, Laura Aldrich-Wolfe, Richard G. Allen, Colleen Webb, Kelly Zamudio, and Alison Power, "Jurisdiction over Endangered Species' Habitat: The Impacts of People and Property on Recovery Planning," Ecological Applications, Vol. 12, No. 3, pp. 690–700, 2002.

Hayhoe, K., D. Cayan, C. B. Field, P. C. Frumhoff, E. P. Maurer, N. L. Miller, S. C. Moser, S. H. Schneider, K. N. Cahill, E. E. Cleland, L. Dale, R. Drapek, R. M. Hanemann, L. S. Kalkstein, J. Lenihan, C. K. Lunch, R. P. Neilson, S. C. Sheridan, and J. H. Verville, "Emissions Pathways, Climate Change, and Impacts on California," Proceedings of the National Academy of Sciences, Vol. 101, No. 34, pp. 12422-12427, 2004.

Hierl, Lauren A., Helen M. Regan, Janet Franklin, and Douglas H. Deutschman, 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, 2005.

Hopkins, John, Regional Conservation Planning in California: A Guide, Institute for Ecological Health, Davis, California, 2004.

Hughes, F. M. R., A. Colston, and J. O. Mountford, "Restoring Riparian Ecosystems: The Challenge of Accommodating Variability and Designing Restoration Trajectories." Ecology and Society, Vol. 10, No. 1, p 12, 2005.

Intergovernmental Panel on Climate Change, "Summary for Policymakers," Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, edited by M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. v. d. Linden, and C. E. Hanson, Cambridge University Press, Cambridge, U.K., pp. 7-22, 2007.

Joyce, L. A., and M. Laskowski, "Natural Resource Managers Respond to Climate Change: A Look at Actions, Challenges, and Trends in the Western USA," Proceedings of the Open Science Conference on Global Change in Mountain Regions, October 2-6, 2005, Sapiens Publishing, pp. 264-266, 2006.

Krist, John, "Humboldt Habitat Conservation Plan Upheld, But Logger Loses Water Ruling," California Planning and Development Report, Ventura, California, Vol. 21, No. 3, March, 2006.

Krist, John, "Court Ruling Offers Warning to Habitat Plan Negotiators," California Planning and Development Report, Ventura, California, Vol. 22, No. 2, February, 2007.

Kueppers, L. M., M. A. Snyder, L. C. Sloan, E. S. Zavaleta, and B. Fulfrost, "Modeled Regional Climate Change and California Endemic Oak Ranges," Proceedings of the National Academy of Sciences, Vol. 102, No. 45, pp. 16281-16286, 2005.

Landis, J. D., R. Pendall, R. Olshansky, and W. Huang, "Fixing CEQA: Options

and Opportunities for Reforming the California Environmental Quality Act," California Policy Seminar, University of California Berkeley, California, 1995.

Legislative Analyst's Office, "Environmental Protection Indicators," Analysis of the 2003-04 Budget Bill, February 19, 2003a.

Legislative Analyst's Office, "Resource Assessments: Improving Effectiveness and Creating Savings," Analysis of the 2003-04 Budget Bill, February 19, 2003b.

Legislative Analyst's Office, Improving the Appraisal Function in Resources Land Acquisitions, Sacramento, California, October 18, 2007.

Legislative Analyst's Office, 2008-09 Budget Overview: Resources Agency Departments, Sacramento, California, March 12, 2008.

Little Hoover Commission, Timber Harvest Plans: A Flawed Effort to Balance Economic and Environmental Needs, Sacramento, California, 1994.

Loarie, S. R., B. E. Carter, K. Hayhoe, S. McMahon, R. Moe, C. A. Knight, and D. D. Ackerly, “Climate Change and the Future of California’s Endemic Flora,” PLoS ONE, Vol. 3, No. 6, e2502, doi:10.1371/journal.pone.0002502, 2008.

Macmynowski, D. P., T. L. Root, G. Ballard, and G. R. Geupel, "Changes in Spring Arrival of Nearctic-Neotropical Migrants Attributed to Multiscalar Climate," Global Change Biology, Vol. 13, pp. 2239-2251, 2007.

Malcolm, J. R., C. Liu, R. P. Neilson, L. Hansen, and L. Hannah, "Global Warming and Extinctions of Endemic Species from Biodiversity Hotspots," Conservation Biology, Vol. 20, No. 2, pp. 538-548, 2006.

McCarty, J. P., "Ecological Consequences of Recent Climate Change," Conservation Biology, Vol. 15, No. 2, pp. 320-331, 2001.

McLaughlin, J. F., J. J. Hellmann, C. L. Boggs, and P. R. Ehrlich, "Climate Change Hastens Population Extinctions," Proceedings of the National Academy of Sciences, Vol. 99, No. 9, pp. 6070-6074, 2002.

Millar, C. I., N. L. Stephenson, and S. L. Stephens, "Climate Change and Forests of the Future: Managing in the Face of Uncertainty," Ecological Applications, Vol. 17, No. 8, pp. 2145-2151, 2007.

Myers, N., R. A. Mittermeier, C. G. Mittermeier, G. A. B. d. Fonseca, and J. Kent, "Biodiversity Hotspots for Conservation Priorities," Nature, Vol. 403, pp. 853-858, 2000.

Nagle, John C., and J.B. Ruhl, *The Law of Biodiversity and Ecosystem Management*, Foundation Press, New York, New York, 2002.

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

Opperman, Jeff J., and Paola Bernazzani, "Comparing Perspectives of Participants and Outside Commentators on Habitat Conservation Plans," Endangered Species Update, Vol. 20, No. 3, pp. 79-90, 2003.

Pollak, Daniel, Natural Communities Conservation Planning (NCCP): The Origins of an Ambitious Experiment to Protect Ecosystems, California Research Bureau, Sacramento, California, March 2001a.

Pollak, Daniel, The Future of Habitat Conservation? The NCCP Experience in Southern California, California Research Bureau, Sacramento, California, June 2001b.

Rahn, Matthew E., Holly Doremus, and James Diffendorfer, "Species Coverage in Multispecies Habitat Conservation Plans: Where’s the Science?," *BioScience*, Vol. 56, No. 7, pp. 613-619, 2006.

Ruhl, J. B., "Regulation by Adaptive Management—Is It Possible?," *Minnesota Journal of Law, Science and Technology*, Vol. 7, 2005.

Ruhl, J.B., “Climate Change and the Endangered Species Act: Building Bridges to the No-Analog Future,” *Boston University Law Review*, Vol. 81, No. 1, February, 2008.

Sagarin, R. D., J. P. Barry, S. E. Gilman, and C. H. Baxter, "Climate-Related Change in an Intertidal Community Over Short and Long Time Scales," *Ecological Monographs*, Vol. 69, No. 4, pp. 465-490, 1999.

San Diego Association of Governments, 2007 Comprehensive Regional Transportation Plan White Paper: Environmental Mitigation Program, Minutes of the Joint Meeting of the Regional Planning and Transportation Committees, San Diego, California, August 4, 2006.

Spencer, W. D., S. J. Barry, S. R. Beissinger, J. L. Florsheim, S. Harrison, K. A. Rose, J. J. Smith, and R. R. White, Report of Independent Science Advisors for Santa Clara Valley Habitat Conservation Plan/Natural Community Conservation Plan (HCP/NCCP), Conservation Biology Institute, Encinitas, California, December 2006.

Stachowicz, J. J., J. R. Terwin, R. B. Whitlach, and R. W. Osman, "Linking Climate Change and Biological Invasions: Ocean Warming Facilitates Nonindigenous Species Invasions." Proceedings of the National Academy of Sciences, Vol. 99, No. 24, pp. 15497-15500, 2002.

Stein, B.A.,. States of the Union: Ranking America's Biodiversity. Arlington, Virginia: NatureServe, 2002.

Stein, B. A., L. S. Kutner, G. A. Hammerson, L. L. Master, and L. E. Morse, "State of the States: Geographic Patterns of Diversity, Rarity, and Endemism," in Precious Heritage: The Status of Biodiversity in the United States, edited by B. A. Stein, L. S. Kutner, and J. S. Adams, Oxford University Press, New York, pp. 119-157, 2000.

Thomas, Gregory A., Where Property Rights and Biodiversity Converge: Lessons from Experience in Habitat Conservation Planning, Natural Heritage Institute, San Francisco, California, 2000.

United States Fish and Wildlife Service, *Conservation Plans and Agreements Database*, *Region 8*, downloaded from http://ecos.fws.gov/conserv_plans/public.jsp on October 24, 2008.

van Mantgem, P. J., and N. L. Stephenson, "Apparent Climatically Induced Increase of Tree Mortality Rates in a Temperate Forest," *Ecology Letters*, Vol. 10, pp. 909-916, 2007.

van Rheenen, N. T., A. W. Wood, R. N. Palmer, and D. P. Lettenmaier, "Potential Implications of PCM Climate Change Scenarios for Sacramento - San Joaquin River Basin Hydrology and Water Resources," *Climatic Change*, Vol. 62, No. 1-3, pp. 257-281, 2004.

Visser, M. E., and L. J. M. Holleman, "Warmer Springs Disrupt the Synchrony of Oak and Winter Moth Phenology," *Proceedings of the Royal Society B*, Vol. 268, pp. 289-294, 2001.

Wayburn, L.E., J.F. Franklin, J.C. Gordon, C.S. Binkley, D.J. Mladenoff, and N. L. Christensen, Jr., Forest Carbon in the United States: Opportunities & Options for Private Lands, for the Pacific Forest Trust, 2007.

Westerling, A. L., H. G. Hidalgo, D. Cayan, and T. W. Swetnam, "Warming and Earlier Spring Increase Western U.S. Forest Wildfire Activity," Science, Vol. 313, pp. 940-943,2006.

Wilcove, D. S., D. Rothstein, J. Dubow, A. Phillips, and E. Losos, "Leading Threats to Biodiversity: What's Imperiling U.S. Species," in Precious Heritage: The Status of Biodiversity in the United States, edited by B. A. Stein, L. S. Kutner, and J. S. Adams, Oxford University Press, New York, pp. 239-254, 2000.

Wilhere, George F., “Adaptive Management in Habitat Conservation Plans,” *Conservation Biology*, Vol. 16, No. 1, February, 2002.

Zavaleta, E. S., and K. B. Hulvey, "Realistic Species Losses Disproportionately Reduce Grassland Resistance to Biological Invaders," Science, Vol. 306, pp. 1175-1177, 2004.

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