The Impact of Climate Change on California's Ecosystem Services

A Paper From:
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Arnold Schwarzenegger, *Governor*

FINAL PAPER

August 2009
CEC-500-2009-025-F

Acknowledgments

We would like to thank The Nature Conservancy of California for support. We would like to thank the following for their generous contributions to the development of this paper: Mel George at the University of California (UC) Davis for his assistance in the development of the forage productivity modeling; Jeff Dozier and Bob Roberts (California Snow Association) and Bridget Ericsson (NSAA) for snowfall data and ski visitation rates in California; Bill Monahan (Audubon – California) and Evan Girvetz (The Nature Conservancy) for their contributions of R scripts and valuable conversations that significantly improved the biodiversity component of this paper; and Steve Polasky (University of Minnesota), Chris Costello (UC Santa Barbara), and Guillermo Mendoza, Driss Ennaanay, and Mark Conte of The Natural Capital Project for their contributions to the development of the valuation components of the paper.

Preface

The California Energy Commission's Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California's electricity and natural gas ratepayers. The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts focus on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

In 2003, the California Energy Commission's PIER Program established the **California Climate Change Center** to document climate change research relevant to the state. This center is a virtual organization with core research activities at Scripps Institution of Oceanography and the University of California, Berkeley, complemented by efforts at other research institutions. Priority research areas defined in PIER's five-year Climate Change Research Plan are: monitoring, analysis, and modeling of climate; analysis of options to reduce greenhouse gas emissions; assessment of physical impacts and of adaptation strategies; and analysis of the economic consequences of both climate change impacts and the efforts designed to reduce emissions.

The California Climate Change Center Report Series details ongoing center-sponsored research. As interim project results, the information contained in these reports may change; authors should be contacted for the most recent project results. By providing ready access to this timely research, the center seeks to inform the public and expand dissemination of climate change information, thereby leveraging collaborative efforts and increasing the benefits of this research to California's citizens, environment, and economy.

For more information on the PIER Program, please visit the Energy Commission's website www.energy.ca.gov/pier/ or contract the Energy Commission at (916) 654-5164.

Table of Contents

List of Figures

List of Tables

Abstract

Ecosystem services are the goods and services—fresh water, soil, biological and genetic diversity, crop pollination, carbon sequestration, climate stabilization, and recreation—that people obtain from intact, natural systems. Ecosystem services play a crucial role in sustaining human well-being and economic viability in California. Californians benefit substantially from the delivery of an array of ecosystem services for which substitutes are costly or completely unavailable. Climate change is likely to substantially alter or even eliminate certain ecosystem services. To better understand the consequences of climate change and to develop effective means of adapting, it is critical that we improve our understanding of the links between climate, ecosystems, and the economic value of ecosystem services. This report projects the impact of future climate change on the natural provision of four key ecosystem services in California (carbon sequestration, forage production, water for instream flows for salmon, and snow recreation) and biodiversity, and the resulting change in market and non-market value of each service. Under most scenarios of climate change, the provision of all four ecosystem services will decline, leading to a decline in the economic output and well-being for the state. The report also reveals that our scientific understanding of the links between climate, ecosystems, and economic value is still poorly developed for California. A comprehensive research program focused on developing models and estimating the impacts of climate change on ecosystem services in California will be an important tool for reversing current and future losses in the economic value of our natural ecosystems.

Keywords: climate change, ecosystem service, valuation, carbon sequestration, biodiversity

1.0 Introduction

1.1. Background and Overview

The United Nations' Millennium Development Goals and the Millennium Ecosystem Assessment highlight the enormous value of the goods and services people obtain from ecosystems and the crucial role these services play in sustaining economic viability (MA 2005 a, b). Ecosystems generate a variety of goods and services important for human well-being, collectively called *ecosystem services.* Ecosystem services are categorized into four types: provisional services (e.g., food, timber, medicines, water and fuels), regulating services (e.g., water purification and carbon sequestration), supporting services (e.g., climate regulation and nutrient cycling), and cultural services (e.g., aesthetic values and sense of place) (MA 2005 a,b). These ecosystem goods and services generate value when they are enjoyed directly by people (e.g., eating fish) or indirectly when they support the production and quality of other things people enjoy (e.g., instream flows support fish). Climate change is likely to affect the abundance, production, distribution, and quality of ecosystem services throughout the State of California including the delivery of abundant and clean water supplies to support human consumption and wildlife, climate stabilization through carbon sequestration, the supply of fish for commercial and recreational sport fishing. For example, as described in this report, areas of the state suitable for forage production to support cattle grazing in natural areas could shift as some parts of the state become too dry to support forage and others become wetter. The ability of the State's forests to sequester carbon and support climate stabilization could be hindered as productivity decreases and fires increase. And increased water temperatures in streams due to a decrease in provision of fresh water could seriously reduce salmon reproduction and subsequently reduce the number of salmon available for commercial and recreational harvest. Also, areas of the state suitable for forage production to support cattle grazing in natural areas could shift as some parts of the state become too dry to support forage and others become wetter. All of these ecosystem services have economic value and that value and its distribution is likely to changes under a changing climate.

But even without climate change, we have consistently failed to properly value the economic contribution of ecosystem services, many of our natural resource decisions have resulted in the loss of these key services and subsequently the loss of the economic values they support. The problem occurs not just in California, but worldwide and is, in part, responsible for a loss of intact ecosystems at the rate of 1% per year. Indeed, 60% of all ecosystem services derived from those ecosystems have been significantly degraded at great financial and human cost (MA 2005 a,b).

Climate change is likely to exacerbate further the loss of ecosystems and the services they support. The effect of climate change on ecosystems and species has been well-documented for terrestrial ecosystems but less so for aquatic and marine ecosystems. Already, there are observable impacts of climate change on terrestrial ecosystems in North America, including changes in the timing of growing season length, phenology, primary production, and species distributions and diversity (Walther 2002; Parmesan 2003). Evidence from two analyses (143 studies, Root 2003; 1700 species, Parmesan 2003) and a synthesis (866 studies, Parmesan 2006) on a broad array of species and ecosystems suggests that there is a significant impact of recent climatic warming in the form of long-term, large-scale alteration of animal and plant populations (Root 2006; Parmesan 2003; Root 2003). If clear climatic signals are detectable above the background of climatic and ecological noise from a 0.6°C (1.1°F) increase in global mean temperature, by 2050 the impacts on ecosystems will be dramatic (Root 2006).

While ecosystems have always changed over time, the ecosystem effects of climate change are likely to be made more severe by the dramatic loss of natural areas we have experienced in the half century. Natural area loss is a primary factor leading to the decline in many important ecosystem services worldwide (MA 2005 a, b), particularly the loss of terrestrial biodiversity (Wilcove et al. 1998; Wilson 1988). As human activity has expanded, the extent of natural habitat has become smaller and more fragmented. Habitat fragmentation and loss is likely to continue because only modest efforts have been made to protect intact ecosystems. To date only 6.1% of land globally, and 15% in California, is designated as in some kind of protected status such as wilderness area, national parks, national monuments, or wildlife refuges (IUCN Categories I-V, UNEP-WCMC 2004)—an amount insufficient to sustain biodiversity or to adequately protect ecosystem services for people into the future. Further, climate and land-use changes alter ecological systems at such a rate that establishing relatively permanent boundaries of protected areas will fail to provide protection for biodiversity and ecosystem services in general. To compound the threat, California's ecosystems and the services they provide are also unusually vulnerable to future climatic change because the geographic boundaries of ecosystems are tightly constrained by topographic features such as mountains and coastlines. Human fragmentation of ecosystems further constrains the natural movement of species and the succession and natural geographic shifting of ecosystems over time (Snyder et al. 2002).

If California ecosystems change dramatically as a result of climate change, the direct value we enjoy from the ecosystem services they produce also will change, in some cases dramatically. This study focuses on a subset of ecosystem services in California, for which we have reasonably good information, and estimates the impacts of climate change on their production and value. To date, we lack a completely developed understanding of the many ways in which climate-driven ecosystem change is likely to affect the economic well-being of Californians and the contribution of ecosystems to the California economy. By focusing on those examples for which we do have some in-depth knowledge, we hope to show the potential magnitude of economic effects that could result from the impacts of climate change on ecosystems.

Our discussions focus on both economic value and economic impact. In this case, *economic value* reflects the degree to which individuals (or society) have higher or lower economic well-being due to the effects of climate change. Economic value from the perspective of consumers of ecosystem services is measured as the amount that the consumer or society would be willing to pay to avoid a negative change in their economic well-being or how much they would be willing to pay to secure an improvement in their economic well-being. For producers, this value closely approximates their profits. For consumers of ecosystem services, the willingness to pay beyond the amount people actually pay is called "their consumer surplus." Because many ecosystem services are available for free to people (e.g., the benefits enjoyed when trees remove carbon from the atmosphere and stabilize the climate) or at low cost (e.g., access to a recreational fishing opportunity), this consumer surplus often is referred to as a *non-market value*. We specifically consider the effect of climate change on the following economic values: the social cost and the market value of carbon sequestration, the profits associated with the production of natural forage, and the consumer surplus of skiing and salmon fishing.

Economic impact differs from economic value in that it represents the exchange of currency, costs, or revenues that may result from a change in ecosystem services. While these values do not reflect the "net" value of ecosystem services, they do reflect the economic activities (including jobs, taxes, and budget outlays) that are associated with the availability of ecosystem services. We examine the potential effects of climate change on the economic impacts associated with meeting the emissions reduction goal of California's Assembly Bill 32 through a cap-and-trade program (e.g., the market price of carbon), the gross revenues earned by the snow sports industry in California, and the gross revenues generated by the salmon commercial and recreational fisheries in California.

We use these examples in the development of a framework for future research to consider the economic impacts of climate change, and adaptation to climate change, on California's climate-sensitive ecosystems. We hope this analysis serves to spur further research into the effects that climate change may have on ecosystem goods and services and ways to combat and adapt to these changes.

1.2. Project Objectives

The goal of this project was to assess the potential impacts of climate change on selected ecosystem services and their associated economic value in California. We look at four important ecosystem services for which we develop projections of the future effects of climate change. Specifically, we focus on the potential effects that climate change may have on two ecosystem services for which we have well-developed estimates of ecosystem change and economic value: (1) *carbon sequestration*, or the ability of terrestrial ecosystems to store carbon, and (2) *forage production*, or the production of natural forage by woodlands and grasslands for cattle. Second, we examine the potential effects that climate change may have on two ecosystem services for which we have only a preliminary understanding of the economic impact of these changes: (1) *water quantity for instream flow for salmon production*, or the effect of climate change on salmon spawning, and (2) *water quantity for recreational skiing*, or the effects of climate change on snow production and skiing. Third, we discuss other ecosystem services about which we currently lack quantitative models, but for which a better understanding may be critically important if we are to fully comprehend the economic consequences of climate change on California ecosystems. Finally, we discuss the impact of climate change on California's rich biodiversity—an ecosystem attribute that that underpins the production of many ecosystem services on which California depends.

In this report, we first quantify the potential impacts of climate change on ecosystem services by determining, quantitatively, the impact of climate change on the provision of four key ecosystem services and biodiversity in California. Because ecosystems and biodiversity are distributed in a heterogeneous way across the state, we use spatially explicit models to project the future patterns of terrestrial ecosystems in California and the production and values of ecosystem services related to carbon sequestration, forage production (an agricultural crop production), and hydrology (water quantity for instream flows). We examine these spatial changes for a future without climate change (neutral climate future) and for each of six future scenario combinations of two greenhouse gas emissions scenarios of climate change (low, optimistic B1 and high, business-as-usual A2) and three general circulation models (the Parallel Climate Model [PCM] which projects a warm and wet future; the Geophysical Fluid Dynamics Laboratory [GFDL] model and the Community Climate System Model, version 3 [CCSM3] which both project hot and dry future). By driving these spatially explicit models with six scenario combinations, we effectively bracket how ecosystem service production and biodiversity are likely to change over time across the many regions of the state under future climate change. In doing so, these models help to highlight areas of particular importance and areas for which the impacts of climate change may be large. The terrestrial ecosystem models incorporate the effects of change in atmospheric temperature, precipitation, and human use patterns and growth. By taking this spatial approach we also can demonstrate how multiple ecosystem services may coincide, providing a better view of which landscapes are more productive and valuable and which are degraded, now and in the future.

We build upon these spatial projections of ecosystem service production by attempting to place an economic value on these ecosystem changes. For carbon sequestration and forage production, we use a growing literature on values to project the potential economic impacts caused by climate change. For instream flows and snow production for recreation, we have only a partial understanding of how changes in these services will affect economic value. For these ecosystem services, we provide an overview of the current economic value of these activities and discuss how these activities are likely to change due to climate-related changes in environmental conditions and precipitation. Finally, we discuss other changes in other ecosystem services and biodiversity, but we do not attempt to place a dollar figure to these changes because there is little agreement in the literature about how to do so. Throughout, we treat each of these services as if they occur in isolation from all other services. In fact, ecosystems are networks of stocks, flows, and services that cross boundaries of both space and time. Our research is intended as a launching point for future, comprehensively integrated research, on the potential impacts of ecosystem change on the productivity and sustainability of the California economy and the economic well-being of Californians.

1.3. Organization

This main body of this report, Chapter 2, provides an overview of the climate change models and data , dynamic global vegetation modeling, species distribution modeling, water provision modeling, forage production modeling, and the valuation modeling for each service.

We divide Chapter 2 into 3 sections: 2.1 Climate Change Models, the 2.2 Effects of Climate Change on Vegetation, and 2.3 Ecosystem Service Modeling and Valuation. Section 2.3 examines the potential economic impacts that may result due to the impact of climate change on ecosystem services. In Section 2.3.1, we provide two case studies of estimates of change for ecosystem services and values (carbon sequestration and forage), in Section 2.3.2 we examine two case studies estimates of ecosystem changes with a discussion of the potential economic value at risk (instream values for salmon and snowpack for skiing and recreation), and in Section 2.3.3 we provide a discussion of other important ecosystem services and values that are likely to change substantially due to climate change.

Chapter 3 provides a synthesis of our findings, their implication for California in the future, and recommends future steps for California's natural resource management in the face of climate change.

2.0 Project Methods: Estimating Climate-Related Changes in Ecosystem Services

2.1. Climate Change Models

2.1.1. Projecting Climate Change

General Circulation Models

To explore the range of impacts on California ecosystem services projected under multiple future climate scenarios, we consider the Intergovernmental Panel for Climate Change's (IPCC's) high (A2) versus low (B1) greenhouse gas emissions scenarios (IPCC 2007); and three atmospheric-oceanic general circulation models (AOGCMs): GFDL-CM2.1 (Delworth et al. 2006), NCAR-CCSM3 (Collins et al. 2006, data only shown for carbon sequestration), and NCAR-PCM1 (Washington et al. 2000). The atmospheric-oceanic general circulation model data were statistically downscaled to 12 kilometer (km) resolution using the bias correction and spatial disaggregation (BCSD) method (Wood et al. 2004; Maurer and Hidalgo 2008; Hugo et al. 2008). Each AOGCM was selected based upon strong regional performance in California (Cayan, pers. comm.) and were selected to bracket future projected extremes ranging from a warm, wet future (NCAR-PCM1) to hot, dry futures (GFDL-CM2.1, NCAR-CCSM3). The California Energy Commission provided data using two downscaling techniques: BCSD and Constructed Analogues (Maurer and Hidalgo 2008; Hugo et al. 2008). A recent analysis indicated that the two methods produce comparable results in downscaled precipitation and temperature at the monthly level (Maurer and Hidalgo 2008). Since the ecosystem service models require monthly data for input, we limited the analysis to the BCSD downscaling method to reduce the number of computationally intensive model runs.

Study Area and Time Periods

The terrestrial area of California was used as the study area for this analysis. To use the downscaled AOGCM data provided by the California Energy Commission, we subdivided the state into a grid of 1/8 degree cells (approximately 12 km on a side). The northwest corner of this grid is 42°N, 124.5°W and the southeast corner is 32.5°N, 114°W, giving the grid 76 rows and 84 columns. Of the 6,384 (= 76 x 84) cells in the grid, only 2,664 correspond to terrestrial locations in California. We summarized our results based on four thirty-year time periods; one historical time period (January 1961 to December 1990) and three future time periods (January 2005 to December 2034, January 2035 to December 2064, and January 2070 to December 2099).

Climate Data

We used three sets of climatic data in this analysis: *historical climate* data generated from interpolating weather station data from 1895 to 2006 across the state; constructed *climate neutral future* based on historical trends from 2005 to 2099 (this *climate neutral future* is designed to simulate climatic conditions without further anthropogenic emissions); and *projected future climate* from the downscaled results of the AOGCMs from 2005 to 2099.

Historical Climate Data

The historical climate data were prepared by the PRISM climate-mapping group at Oregon State University (PRISM Group, www.prism.oregonstate.edu/). Eight-hundred meter grain climate data were resampled to the 12 kilometer grain study area grid using a Gaussian filter. Data from 1895 to 2006 for four variables were provided: average monthly minimum temperatures (T_{min}), average monthly maximum temperatures (T_{max}), precipitation (ppt), and dewpoint temperature (T_{dmean}).

Neutral Climate Future Data

To generate changes in ecosystem services through 2099, we developed a set of neutral climate future with no further anthropogenic emissions derived from detrended historical data from 1895 to 2006 with averages based on mean climate data from 1992 to 2006.

Future Climate Scenarios Data

We used downscaled Atmospheric-Oceanic General Circulation Model (AOGCM) climate variables include monthly values for $T_{min,}$ T_{max}, and ppt from 2005 to 2099. To remove some of the AOGCM-specific biases, we generated climate departures or anomalies for each AOGCM and emissions scenario combination, using the 30-year neutral climate future period of record 1960 to 1990. These departures were added to the historical 1960 to 1990 average monthly data to generate a time-series of simulated climate data starting in 2005.

2.1.2. Projected Climatic Changes

When averaged across the state, both minimum and maximum temperatures are projected to increase in all AOGCM and emissions scenario combinations in all time periods (Table 1). The projected maximum temperature increases range from 0.6°C to 1.3°C (1.1°F to 2.3°F) in the first time period (2005–2034); 0.8°C to 2.3°C (1.4°F to 4.1°F) in the second time period (2035–2064); and 1.5°C to 4.2°C (2.7°F to 7.6°F) in the final time period (2070–2099) (Figure 1). The projected patterns are similar for statewide minimum temperature increases. The GFDL and CCSM3 models project similar amounts of warming, while the PCM1 model projects on average 1°C (1.8°F) less warming for each emissions scenario and time period.

Table 1. State averages by time period, model, scenario, showing historical and projected future temperature and precipitation

Scenario	Model	2005–2034			2035–2064			2070–2099		
		Min Temp (C)	Max Temp (C)	Precipitation (mm)	Min Temp (C)	Max Temp (C)	Precipitation (mm)	Min Temp (C)	Max Temp (C)	Precipitation (mm)
1961–1990		*6.8*	*21.3*	*52.3*						
B1	PCM1	7.3	21.9	58.4	7.6	22.2	55.4	8.4	22.9	55.7
	CCSM3	8.0	22.6	48.8	8.6	23.2	52.1	9.1	23.7	52.3
	GFDL	8.0	22.6	53.9	8.8	23.3	51.4	9.3	23.9	47.3
A2	PCM1	7.3	21.9	53.9	8.0	22.6	53.4	9.4	23.8	54.1
	CCSM3	7.9	22.5	50.7	9.1	23.6	49.5	11.0	25.5	49.3
	GFDL	8.2	22.7	52.5	8.9	23.5	51.3	11.1	25.5	43.0

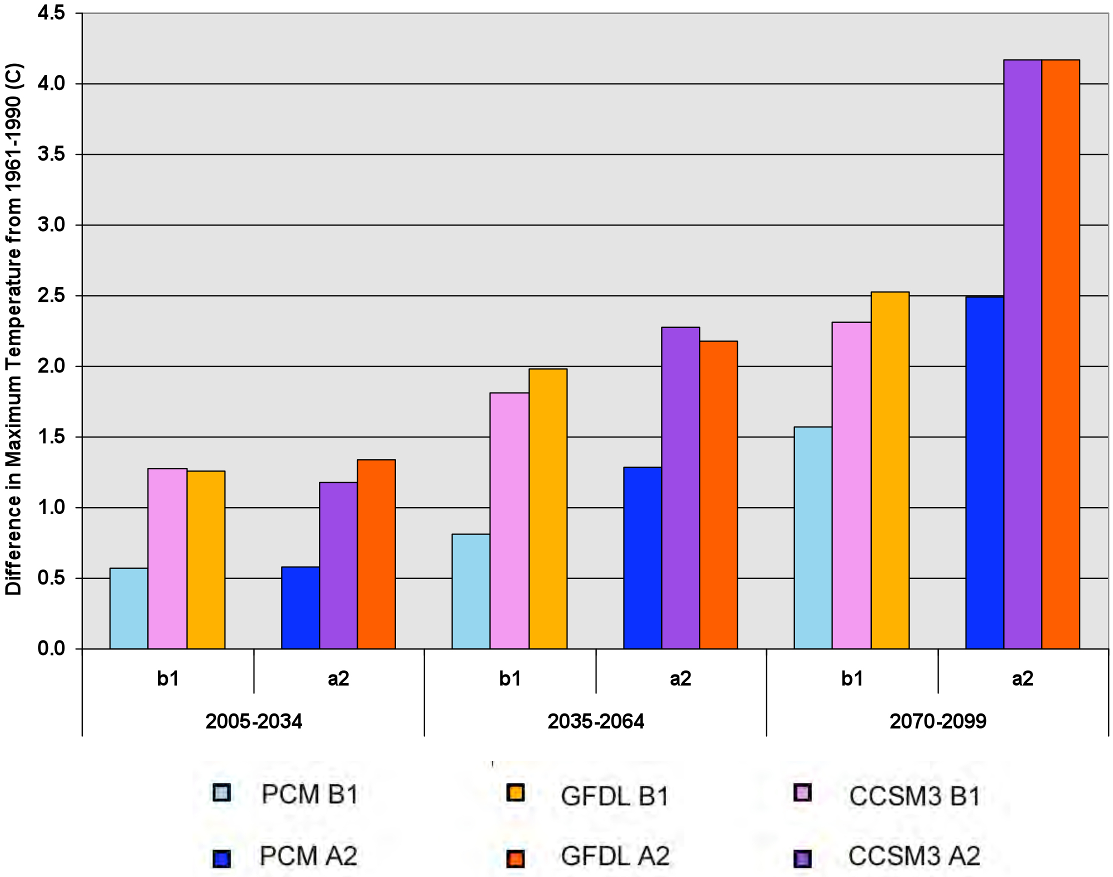

Figure 1. Projected change in average annual maximum temperatures statewide by time period, scenario and climate model

Projected precipitation changes are more variable across the six future scenario combinations than temperature. The PCM1 model projects a net increase in precipitation for all time periods and emissions scenarios, with a greater increase under the B1 emissions scenario (Figure 2). The CCSM3 model under the B1 emissions scenario projects a 6% decrease in precipitation during the 2030s, but this effect erodes to no projected change by the end of the century. CCSM3 also projects a consistent 3%–6% drop under the A2 emissions scenario. The GFDL model projects a slight increase in precipitation in the first time period under both emissions scenarios, but then drops to the greatest decrease in precipitation by 2070–2099. Under the A2 emissions scenario, GFDL projects an average of an 18% decline in precipitation across the state by the end of the century.

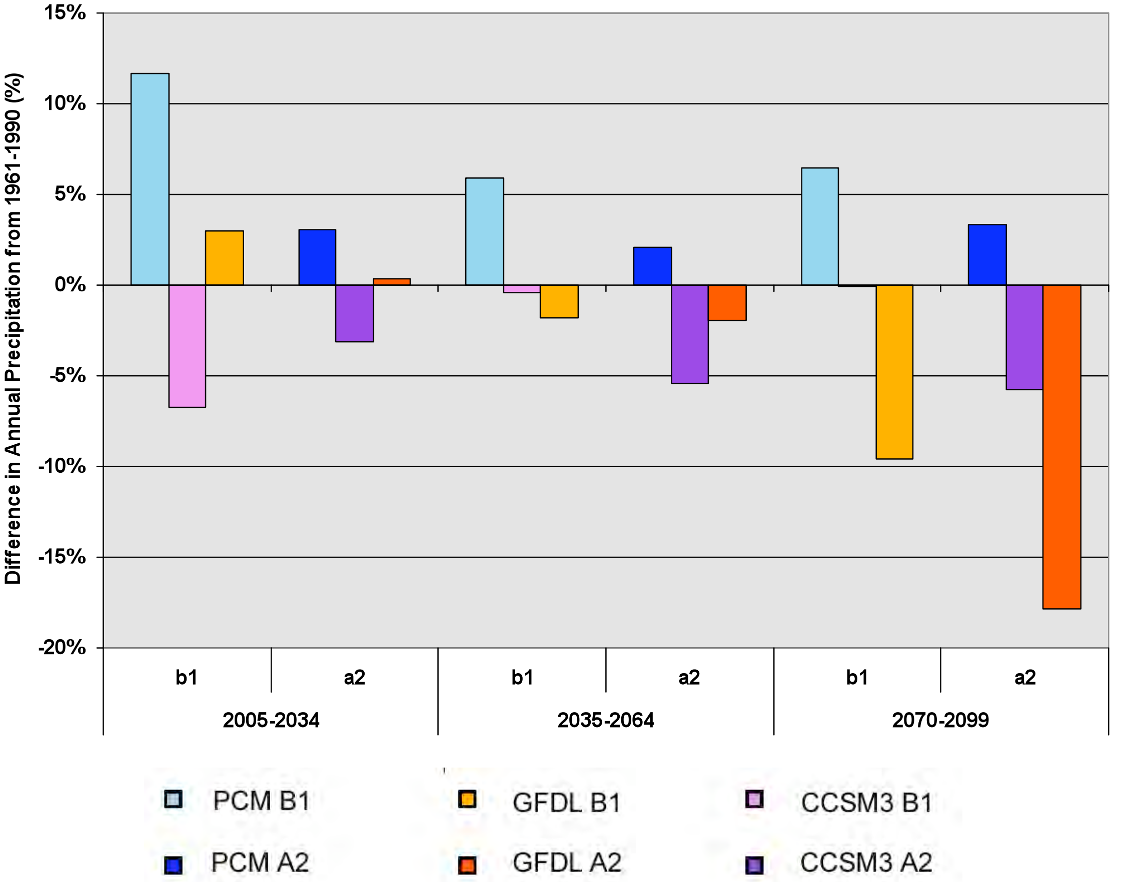

Figure 2. Projected change in average annual precipitation statewide by time period, scenario and climate model

2.2. The Effects of Climate Change on Vegetation

2.2.1. Dynamic Global Vegetation Model

Ecosystem services are highly dependent on vegetation cover, type, and distribution. To project changes in vegetation distribution throughout California, we used the MC1 Dynamic Global Vegetation Model (MC1-DGVM) developed by the U.S. Forest Service (USFS) and Oregon State University at the Forestry Sciences Laboratory, Corvallis, Oregon. MC1 is a dynamic vegetation model that estimates the distribution of vegetation and associated carbon, nutrients, and water fluxes and stocks. It has been used previously to simulate potential vegetation shifts in California (Lenihan et al. 2003, 2008 a, b; Hayhoe et al. 2004) and Alaska (Bachelet et al. 2005), all of North America, and for the entire globe under various climate change scenarios (www.fsl.orst.edu/dgvm/). It consists of three modules that simulate the changes in the biogeography, biogeochemistry, and fire regime over time. The biogeography module simulates the potential lifeform mixture of evergreen needleleaf, evergreen broadleaf, deciduous broadleaf trees, and C3 and C4 grasses (Bachelet et al. 2003). The biogeochemistry module is a modified version of the CENTURY model (Parton et al. 1994), which simulates plant productivity, organic matter decomposition, and water and nutrient cycling (Bachelet et al. 2004). The fire module (Lenihan et al. 2008b) simulates the occurrence, behavior, and effects of fire. The fire module consists of several mechanistic fire behavior and effect functions (Rothermel 1972; Peterson and Ryan 1986; van Wagner 1993; Keane et al. 1997) embedded in a structure that provides two-way interactions with the biogeography and biogeochemistry modules (Lenihan et al. 2003). The model is used by the USFS to forecast fire probabilities and area burned, throughout the United States (www.fs.fed.us/pnw/mdr/mapss/fireforecasts).

We ran MC1 model for both historical and future climate conditions and documented changes in (1) carbon stocks (leaves, branches, roots), (2) soil carbon content and moisture that describe carbon sequestration potential and water stress; (3) wildfire occurrence and impacts that estimate carbon losses and the changes in the recovery potential of the ecosystems if/when the fire regime changes; and (4) vegetation cover that will affect species range and extent and ecosystem service production.

2.2.2. MC1-DGVM Input Data

The MC1 model requires a monthly time series of four climate variables (T_{min}, T_{max}, ppt, and VPR). Vapor pressure is calculated using dewpoint temperatures.

The MC1 model also requires elevation and several soil characteristics (soil depth, soil texture, bulk density and rock fragment content). We generated the mean elevation for each 12 km grid cell based on a finer scale (30 meter) digital elevation model created by the U.S. Geological Survey (USGS). The soil datasets were downloaded from the Soil Information site at Pennsylvania State University (www.soilinfo.psu.edu/index.cgi?soil_data&conus&data_cov). These are multi-layer soil characteristic data that are based on the U.S. Department of Agriculture (USDA) State Soil Geographic Database (SSURGO). Since the MC1 model requires “top, mid, and deep” soil layers (0–50 centimeters [cm], 50–150 cm, >150 cm), but the source datasets are divided into 11 layers, the layers were grouped and an average value calculated, with layers 1–6 corresponding to the first of three soil layers, 7–9 with the second and 10–11 with the third. The raster datasets were then resampled to a 12 km resolution from the original 1 km cell size, calculating a mean value for each 12 km grid cell for each of the three soil layers.

2.2.3. MC1-DGVM Application

We completed the four phases of model runs with MC1. The first phase is the “equilibrium” run that generates an initial potential vegetation map with associated carbon pools (e.g., carbon stocks in the soil, nitrogen stocks in plants) obtained after equilibrium is reached with long term climate and prescribed fire regimes. The second phase is the “spin-up” run which allows dynamic fire events and the establishment of a reasonable fire return interval given detrended historical climate time series. During the third or “historical” phase the model is run using uncorrected historical climate data. Finally, the neutral climate future and the six combinations of AOGCM and CO2 emissions scenario climate data are used in the fourth or “future” phase to project future changes.

For the equilibrium runs, the MAPSS equilibrium biogeography model (Neilson 1995) is run using with one year of climate data (based on the mean 1895–2006 data) and current soil and elevation data. The equilibrium run terminates when the slow soil organic matter stock reaches steady-state, which may require up to 3000 simulation years for certain vegetation types (Daly et al. 2000). Because the dynamic fire module in MC1 cannot be run meaningfully without interannual variability, fire frequency is prescribed for each vegetation type during this equilibrium phase. The spin-up phase is run using detrended historical climate data using target means based on mean climate data from 1895 to 1909. The spin-up period is generally at least 500 years or until NEP (net ecosystem production) for the region of study nears zero. During the historical phase , the model runs using the original 1895–2006 historical climate data, and during the future phase it uses the data generated with the ,monthly anomalies from the seven different future scenarios between 2005 and 2099. MC1 was run without nitrogen limitation (biological nitrogen fixation is assumed to provide enough nitrogen to allow plants to maintain at least a minimum carbon-to-nitrogen [C/N] ratio in all plant compartments when mineral soil nutrients becomes insufficient to meet the demand) and without fire suppression for this project.

We developed a new calibration of the biogeography rules specifically for this project. Our objective was to calibrate the model to match closely the observed vegetation patterns in California (excluding urban and agricultural areas). The observed data used to calibrate the model consisted of a map of current vegetation aggregated based on the California Wildlife Habitat Relationship class (WHR10NAME) (http://frap.cdf.ca.gov/data/frapgisdata/download.asp?rec=fveg02_2).

2.2.4. The Response of Vegetation Distribution to Future Climate Scenarios

The MC1 DGVM projects widespread changes in vegetation across the state by the end of the century. The most pronounced change consistent across AOGCMs and emissions scenarios is a 15% to 70% increase in shrublands when compared to the neutral climate future scenario (Figure 3). In addition, there is a consistent decline in conifer woodland, conifer forest and herbaceous cover across the AOGCMs and emissions scenarios through the end of the century. The hot, dry GFDL model projects an increase in shrubland, desert shrubland, and hardwood forest and a decrease in grassland and conifer woodland and conifer forest under both CO_2 emissions scenarios. The warmer, wetter PCM1 model projections are less pronounced and vary by emissions scenario, with the exception of a 10-20% increase in hardwood woodland and a decrease in conifer woodland and for conifer forest (~10%).Shrublands are projected to decrease (<10%) under the B1 emissions scenario but to increase (~30%) under the A2 emissions scenario.

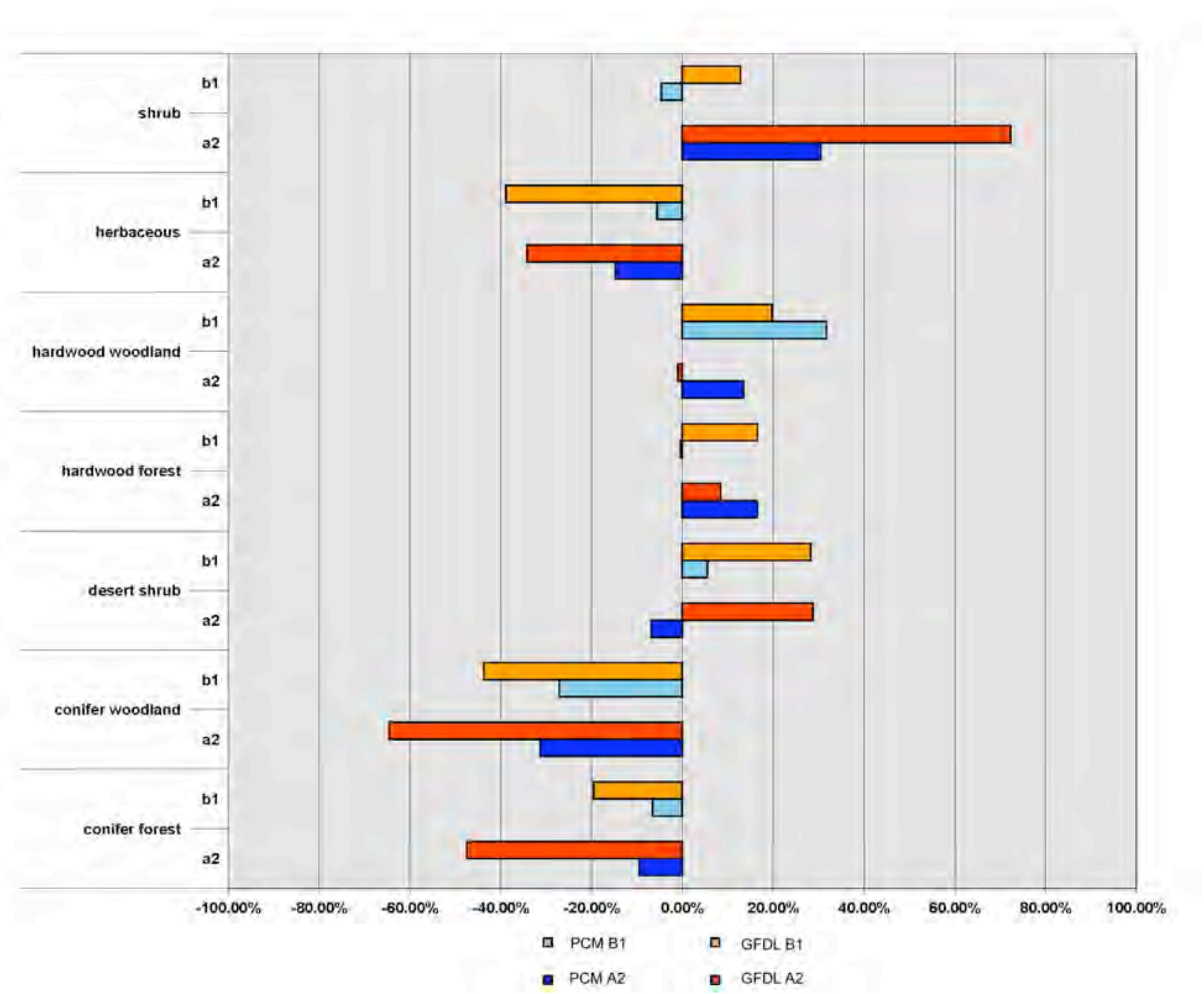

Figure 3. Percent change in areal extent of major vegetation types projected by 2070–2099. The chart shows the difference between the areal extents of vegetation types in 2070–2099 as compared to the base scenario for that time period.

The spatial distribution of the projected vegetation changes by 2070 to 2099 are presented in Figure 4. The map labeled "Historical" reflects the modal potential natural vegetation simulated for the period spanning 1961 to 1990. The expansion of the hardwood forest into the Sierra, Modoc, Klamath, and North Coast ecoregions is evident in all future scenarios, but it is most pronounced with the GFDL climate under the A2 scenario. In all model-emissions scenario combinations, shrublands expanded north along the coast into the Central Coast, into the southern Sierra, the Sacramento Valley and the Modoc. Desert shrubland expands into the San Joaquin valley in the GFDL models, but retreats in the PCM1 model along the coast, with greater shifts projected in the interior of the state. Appendix A presents the full extent of all vegetation types for three time periods of interest. Hardwood woodlands are projected to decline in the Sacramento valley under the hot, dry GFDL model, but a thin belt is preserved along the Sierra foothills under the more aggressive A2 emissions scenario. In general, the vegetative communities are projected to be more stable.

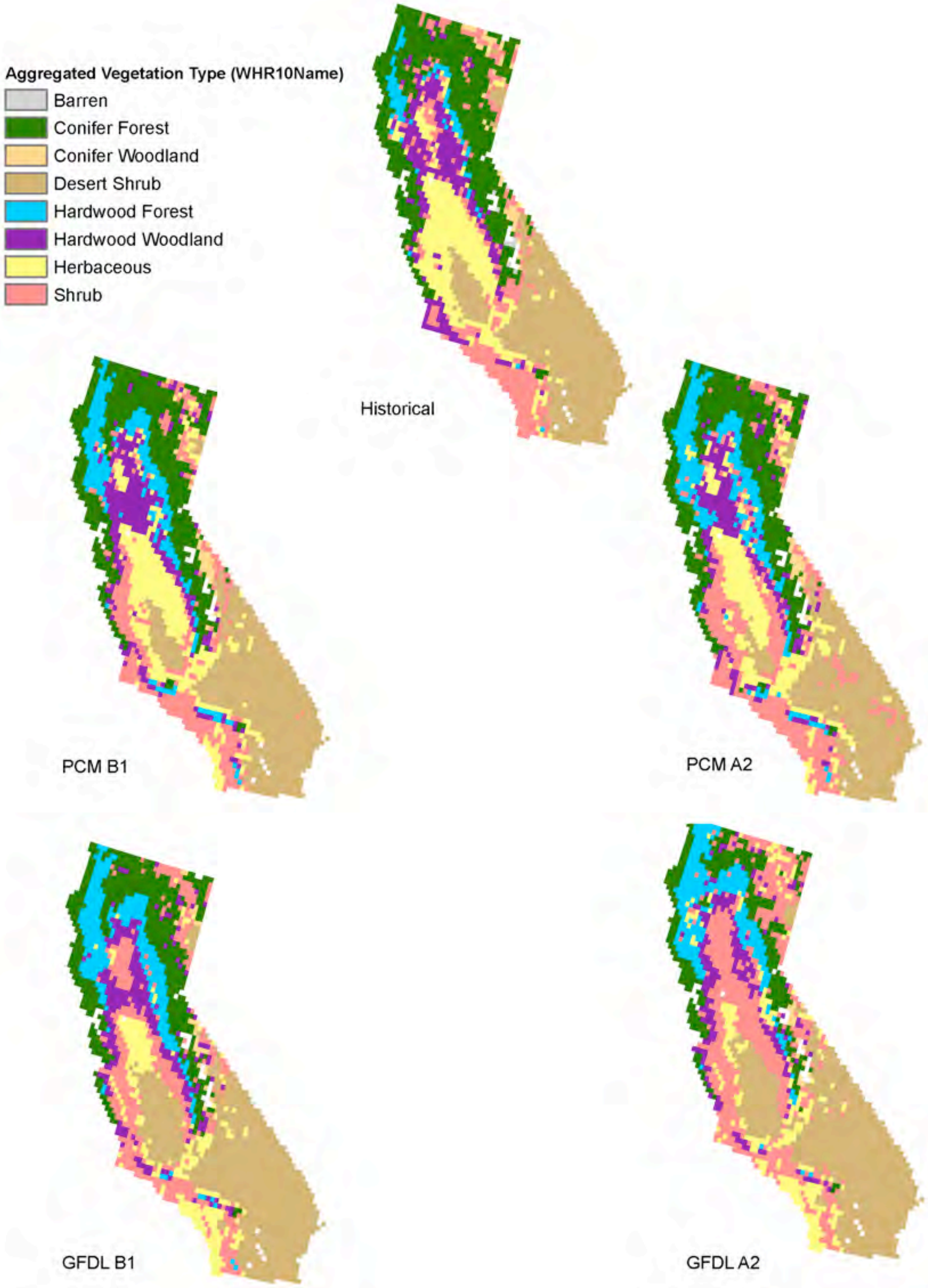

Figure 4. Distribution of major vegetation types during historical time period (top of figure) and at the end of the 21st century (modal values for the period 2070–2099)

2.3. Ecosystem Service Modeling and Valuation

2.3.1. Projecting Ecosystem Service and Value Change: Two Case Studies

Carbon Sequestration

Carbon sequestration is a regulating ecosystem service. It is an important component of California's overall strategy for mitigating the increasing emissions of carbon dioxide (CO_2) into the atmosphere. There are estimates that California's terrestrial ecosystems could sequester significant quantities of carbon over the next 50 years; however, the amount of carbon stored will be highly dependent on future climatic changes and their impact on California's ecosystems. *Carbon sequestration* in terrestrial ecosystems is defined as the net removal of CO_2 from the atmosphere into long-lived stocks of carbon. The stocks can be living, aboveground biomass (e.g., trees), living biomass in soils (e.g., roots, microorganisms), or organic and inorganic carbon in soils. To provide the service of climate regulation through carbon sequestration, carbon must be fixed into long-lived stocks such as trees or soil, as it is not sufficient to alter the size of fluxes in the carbon cycle (e.g., increase primary productivity). In this study, we project changes in carbon storage in aboveground biomass in trees, as well as the associated long-term carbon stocks.

Carbon Sequestration Modeling

To determine ecosystem service values associated with carbon storage and sequestration, we report results for all ecosystem carbon stocks but we focus the analysis on above-ground live tree carbon since there is an existing protocol within the California Climate Action Registry for securing carbon offsets under a cap and trade program capitalizing on the carbon stored in trees[1] (www.climateregistry.org/tools/protocols/project-protocols/forests.html) and on total ecosystem carbon (above- and below-ground live biomass, above- and below-ground dead carbon, and soil). We assume active management of ecosystem carbon stocks. The MC1 model generates the monthly amounts of carbon stored or lost in each grid cell each year under historical, and neutral future climate conditions , or under projected future climate change scenarios. We accounted for urban expansion impacts on carbon sequestration potential by including current and future urban growth. For the neutral future climate scenario, we used the Multi-source Land Cover data to calculate the percentage of landcover in urban or agriculture uses in 2000 (CDF 2002). The agricultural extent represents row crops and other intensive agriculture, not rangelands or timberlands. Under future conditions, we used the mid-range projections for household density generated for this project by Lawrence Livermore National Laboratory and set a threshold of 1 unit per hectare as the minimum density for "urban." This density may lead to an overestimation the amount of carbon that would remain in suburban areas in forested landscapes, but given the focus on carbon stored in natural landscapes for this study, this housing density cutoff is appropriate. The agricultural extent decreased under future

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[1] In October 2007, the state of California's Air Resources Board (CARB) adopted California Climate Action Registry (CCAR) protocols, which established methods to calculate carbon credits for forestland owners. Current CCAR forest protocols require calculation of project carbon credits as live tree biomass (tree bole [trunk], roots, branches, leaves/needles) and dead tree biomass (standing and lying dead wood).

conditions as urbanization expands as we did not model the future expansion of agriculture. The projected urban extent in 2035, 2065, and 2100 was calculated for each 1/8 degree grid cell and combined with the current agricultural extent to generate a combined “converted land” extent. The percentage of the remaining natural cover in each cell was multiplied by the carbon and forage production values to account for the additional impact of future urbanization on these services. We took the average of the summed annual values for each of the four 30-year time periods and subtracted the projected carbon stocks for the six combinations of emissions scenario and AOGCMs from the carbon stocks generated for the neutral climate future dataset.

Projections of Future Carbon Sequestration

The impact of future climate on carbon sequestration will vary if the climate becomes warmer and wetter, as projected by the PCM1 model, or hotter and dryer, as projected by the GFDL and CCSM3 models. Using the warmer, wetter model (PCM1), an increase in aboveground carbon storage relative to the neutral climate future scenario is projected under both the low (B1) and high (A2) emissions scenario in comparison with the neutral climate future scenario (Figure 5). In contrast, under the hotter, drier model (GFDL), MC1 projects much lower carbon stocks than it does under neutral climate future scenario, with steep declines by the end of the century under the A2 emissions scenario. The future climate generated by CCSM3 causes an even sharper decline in carbon stocks over the next century, with the largest loss simulated under the A2 emissions scenario. In summary, by the end of the century, carbon stocks increase by 9% under a warmer, wetter future, or drop by 26% under a hotter, drier future (Figure 6). It is important to note that even without increasing greenhouse gas emissions, there is a decline in carbon stored under the future climate neutral scenario due to urbanization and increasing fire frequency extent. Our analysis show that land use increased aboveground carbon loss, on average across all emissions scenarios and model combinations, by an additional 1.5% by the end of the century. In addition, the future climate neutral scenario uses detrended climate data (from 1895–2006), rescaled to the means of 1992–2006 climate so some of the neutral climate future decline due to fire is a response to current day climatic change resulting from historical greenhouse gas emissions.

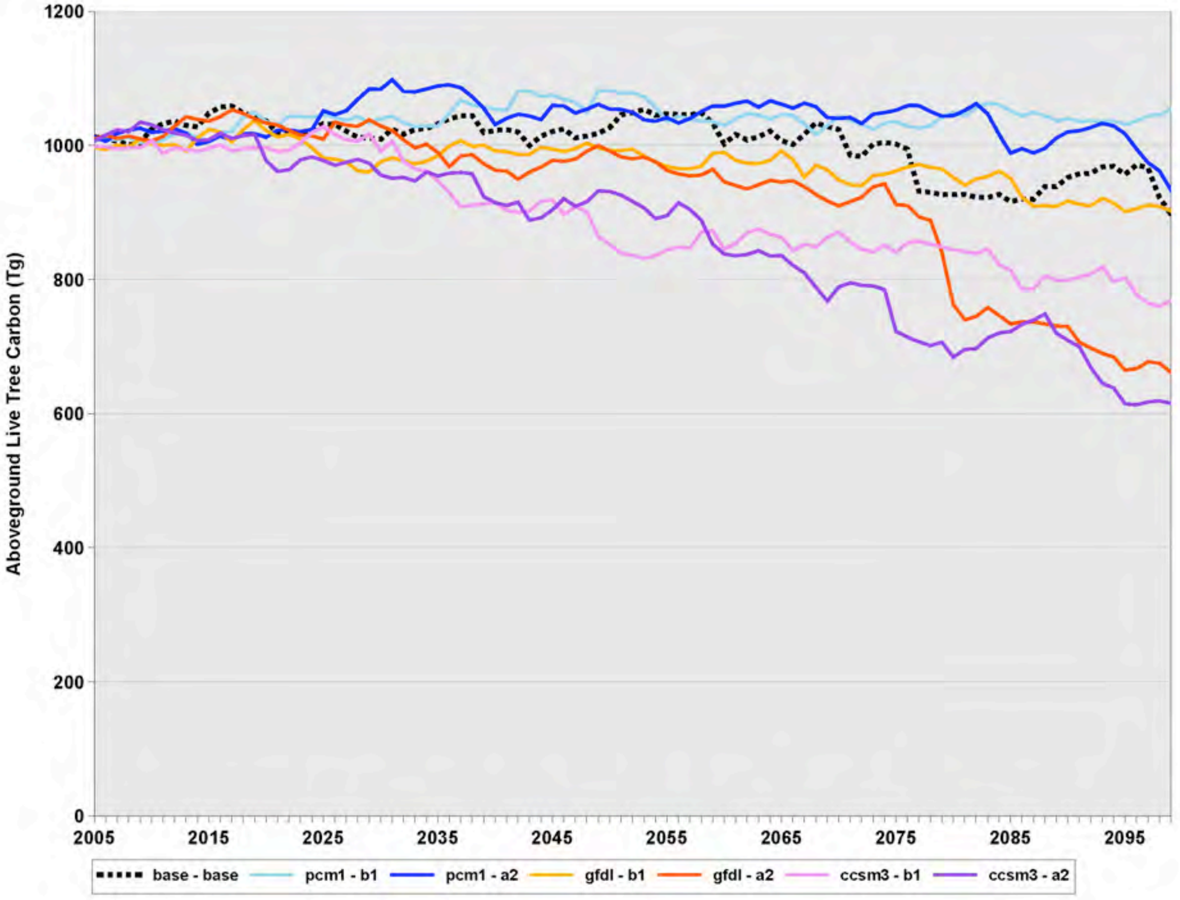

Figure 5. Simulated annual carbon stored in aboveground live trees (in teragrams, Tg) from 2005 to 2099 for neutral climate future conditions and, low, and high emissions scenarios for three AOGCMs (PCM1, GFDL, and CCSM3) simulated climate conditions

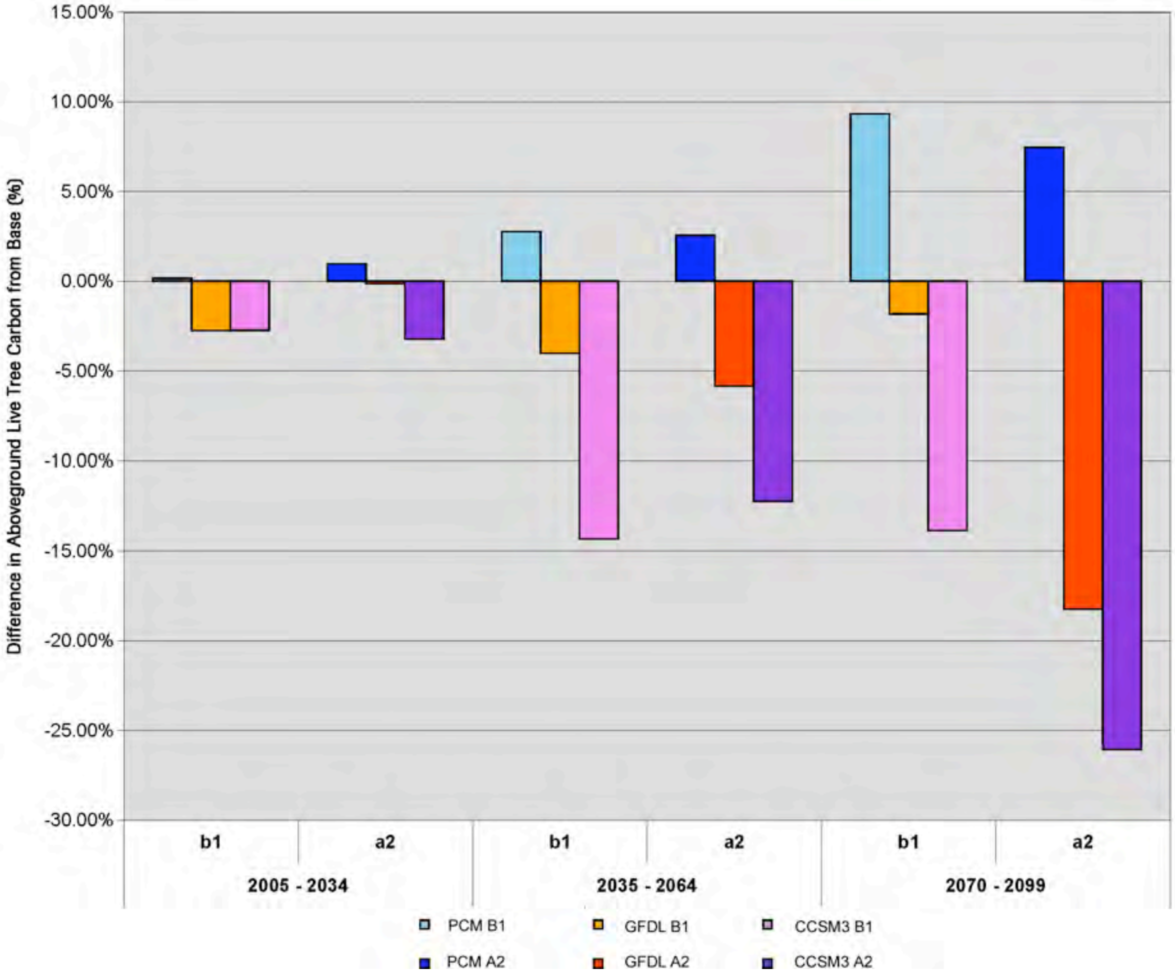

Figure 6. Percent change from the neutral climate future in carbon storage in aboveground live tree biomass under low and high emissions scenarios for three AOGCMs (PCM1, GFDL, and CCSM3) simulated climate conditions

The spatial pattern of carbon storage in aboveground live carbon stocks changes dramatically across the state by the end of the century, depending on the future emissions scenarios and the AOGCM used (Figures 7 and 8). Under both the low and high emissions scenarios, there is a large increase in carbon stocks in the northwest of the state under the warmer, wetter climate conditions projected by PCM1. Total carbon storage in live trees increases statewide, outweighing the losses in carbon in the Sacramento Valley and the Coast Range (Figure 7). Under both low (B1) and high (A2) emissions scenarios, large losses in aboveground live carbon stocks are projected in the eastern Sierra under future conditions simulated by the GFDL model, and in the Klamath Mountains and Modoc Plateau under a future simulated by the hot and dry CCSM3 model. Under the A2 emissions scenario, there are relatively few areas projected to increase carbon storage under the hotter, drier conditions simulated by GFDL and CCSM3.

Even though the current protocols for current voluntary and future regulatory markets of ecosystem carbon storage in California only considers carbon stored in aboveground tree live biomass. To fully understand the impact of climate change on the role of natural systems in storing carbon in the future, it will be necessary to account for the carbon stored in all ecosystem stocks including soils. In this analysis, total carbon stored in the combined stocks of ecosystem carbon (aboveground live biomass, aboveground dead biomass, belowground live biomass, and soil carbon) exhibits a similar trend to the aboveground live tree stock alone, but with a lower magnitude of relative change in storage because of the influence of the largest carbon stock (soil, Appendix B). In a warmer and wetter future (PCM1), the difference with the climate neutral scenario for the 2070–2099 time period is an *increase* of 3% for the B1 emissions scenario and an *increase* of 4% for the A2 emissions scenario (see Appendix B). However, the projected difference by the hotter, drier model (GFDL) is a *decrease* of 1% under the B1 emissions scenario and a *decrease* of 4% for all stocks under the high (A2) emissions scenario. The largest drop of carbon stored in all stocks is simulated by the hot and dry CCSM3 projections, in which there is a 3% and a 5% decrease under the B1 and A2 emissions scenarios, respectively.

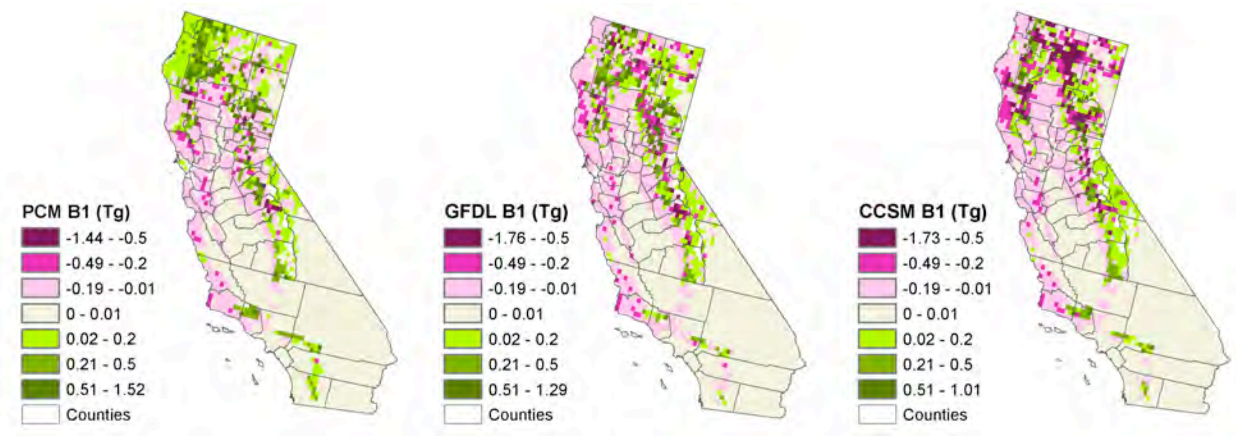

Figure 7. Net change in aboveground live tree carbon stored by the end of the century (2070–2099 mean) under the low B1 emissions scenario in comparison to the neutral climate future scenario and three AOGCMs (PCM1, GFDL, and CCSM3) simulated future climate conditions in Tg. Dark purple represents the low carbon storage, and the dark green represents high carbon storage.

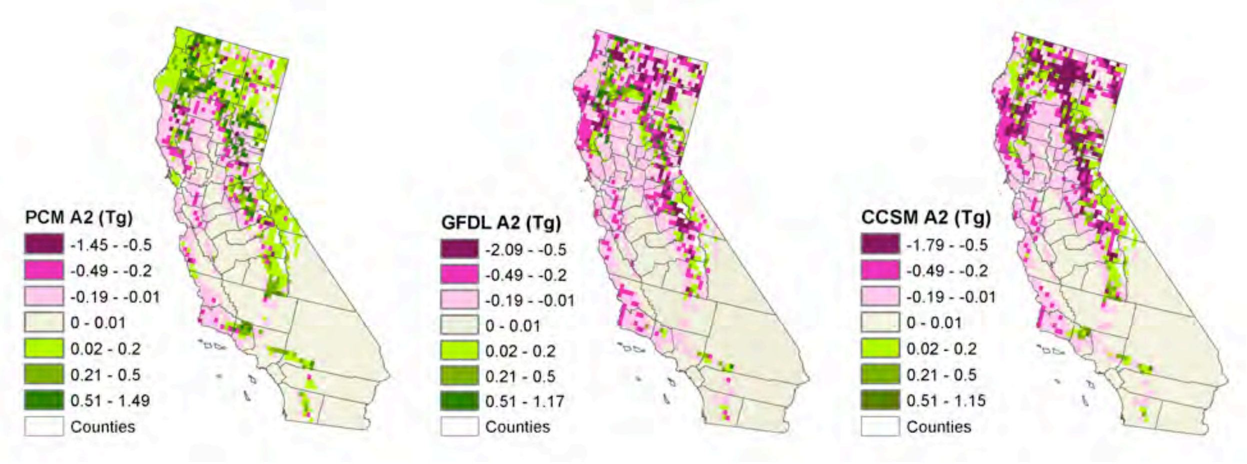

Figure 8. Net change in aboveground live tree carbon stored by the end of the century (2070–2099 mean) under the high A2 emissions scenario in comparison to the neutral climate future scenario and three AOGCMs (PCM1, GFDL, and CCSM3) simulated future climate conditions in Tg. Dark purple represents the low carbon storage, and the dark green represents high carbon storage.

Fire plays an increasingly significant role in decreasing carbon stored in the aboveground live tree stocks over the next century, even in the neutral climate future scenario (Figure 9). The amount of carbon in biomass consumed by fire rises in all of the scenarios on average statewide under the B1 emissions scenario, with the PCM1 climate conditions generating the smallest increase (Figure 9). Yet the neutral climate future scenario has the steepest trendline emphasizing the importance of the large warm and dry fire years in the late twentieth century in triggering a strong vegetation response to this recent warming trend (Figure 9).

Under the high A2 emissions scenario and all future climate conditions, the model simulates an increase in the amount of carbon in biomass consumed by fire over this century, with the climate neutral scenario showing the least change (Figure 10) and the hotter and drier CCSM3 and GFDL models show a similar trend with an increasing role of fire in removing aboveground biomass.

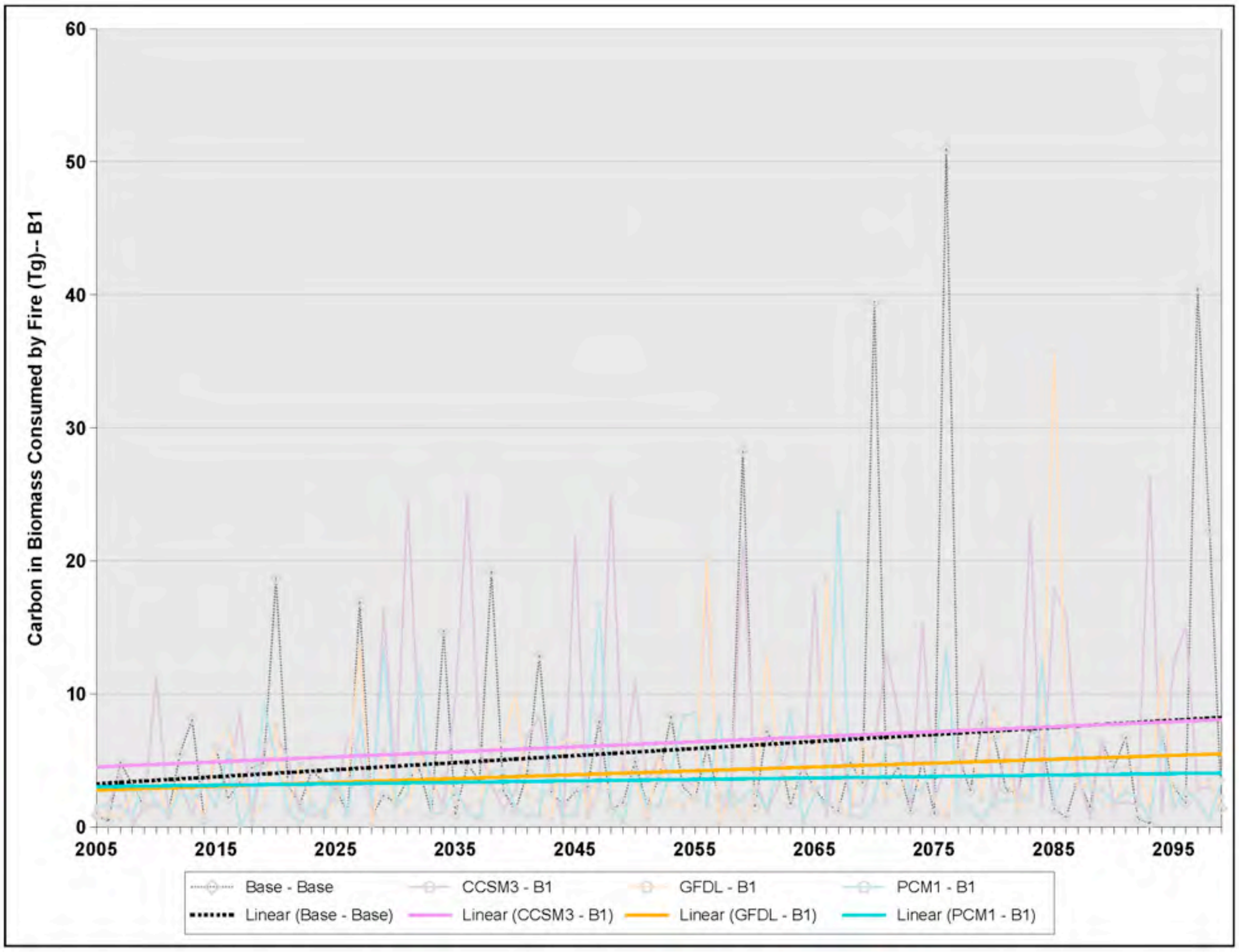

Figure 9. Trend in the amount of biomass consumed by fire under the climate neutral scenario and three future AOGCMs future climate conditions under the low emissions (B1) scenario. The trendline of the climate neutral scenario is actually steeper than any of the climate change scenarios suggesting that future moderate climate conditions will cause a greater decrease in production (as illustrated in Figure 5) than climate conditions similar to those of the last 10–15 years thus ultimately causing a decrease in fuel production and also a decrease in fuel moisture that will reduce fire-induced carbon losses but increase carbon losses due to straight-forward drought-stress.

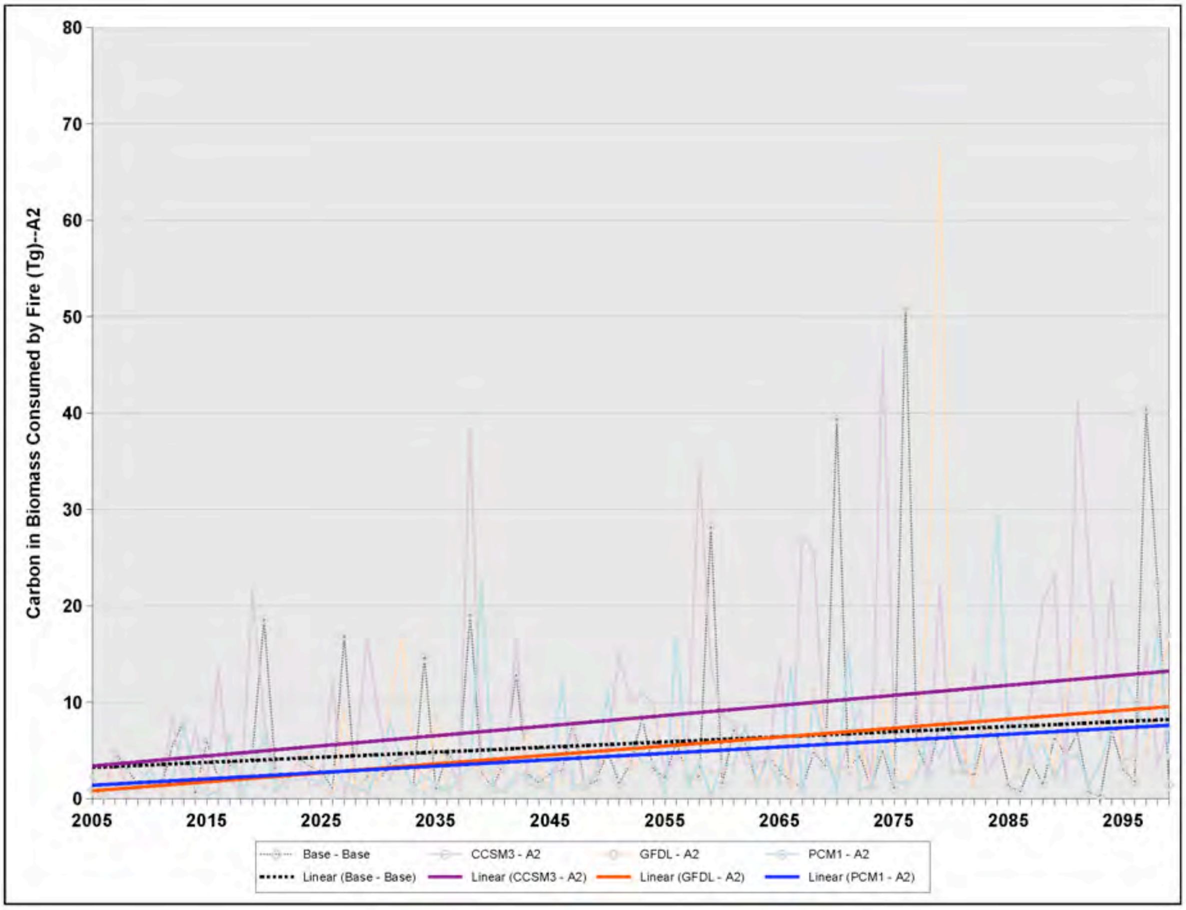

Figure 10. Trend in the amount of biomass consumed by fire under the climate neutral scenario and three future AOGCMs future climate conditions under the low emissions (A2) scenario

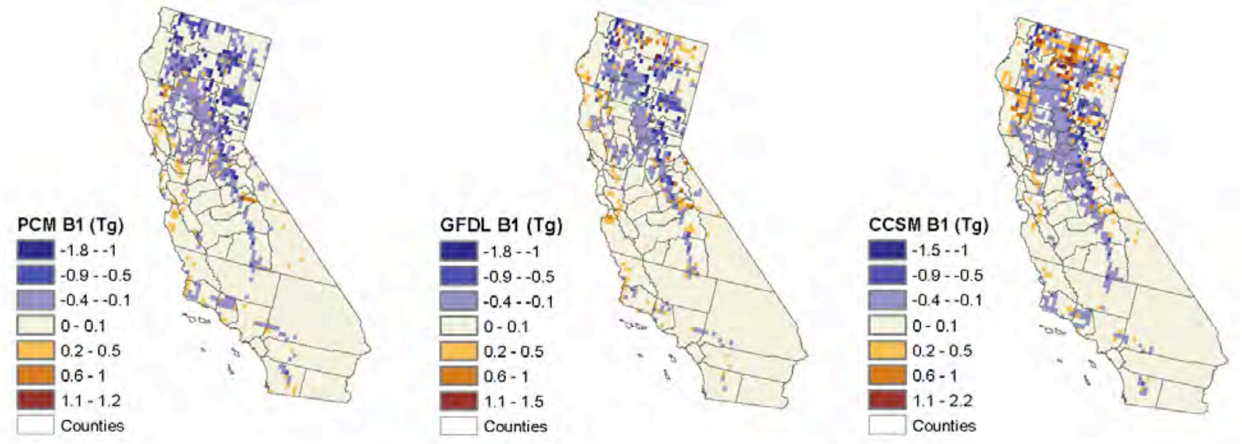

Figure 11. Net change in carbon in biomass consumed by fire by the end of the century (2070–2099 mean) under the low B1 emissions scenario between the neutral climate future scenario and three AOGCMs (PCM1, GFDL, and CCSM3) simulated future climate conditions. Dark blue represents areas where historically fire consumed more than is projected by the end of the century on average and

dark orange is where fire is expected to consume more biomass than historical levels.

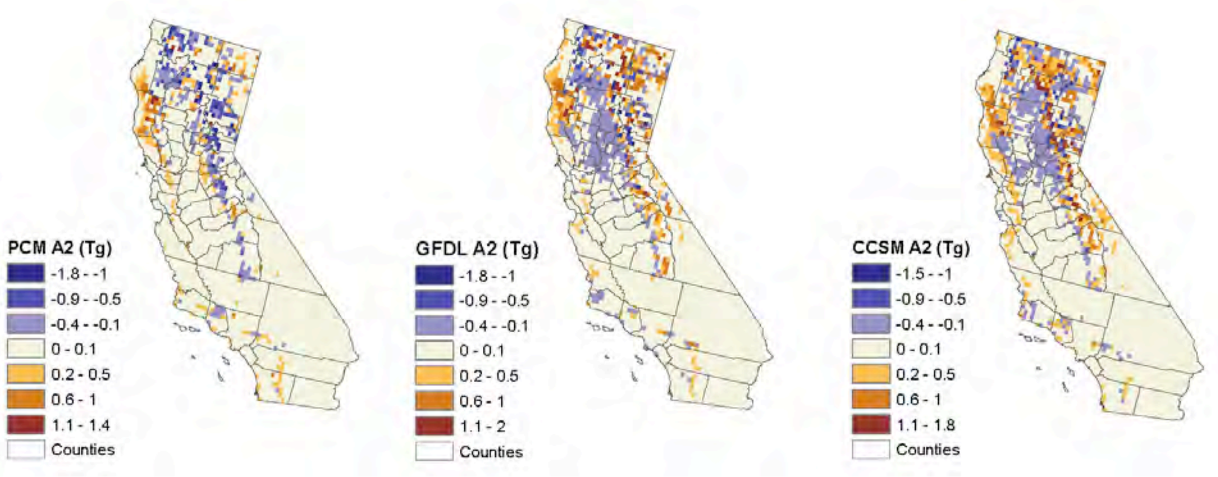

Figure 12. Net change in carbon in biomass consumed by fire by the end of the century (2070–2099 mean) under the high A2 scenario between the neutral climate future scenario and three AOGCMs (PCM1, GFDL, and CCSM3) simulated future climate conditions. Dark blue represents areas where historically fire consumed more than is projected by the end of the century on average and dark orange is where fire is expected to consume more biomass than historical levels.

Carbon Sequestration Valuation

The sequestration of carbon generates both market value, through constructed markets for carbon emissions, and a more comprehensive social value. The market value of carbon reflects the least-cost method for reducing carbon emissions in the atmosphere, as revealed by the market. The social value of carbon sequestration (also known as the social cost of carbon) reflects the global economic consequences of each ton of carbon released into the atmosphere.

To estimate the market and economic values of carbon over time we consider how much carbon will be stored in live trees above ground under the base future climate scenario and under each climate change scenario. We then estimate the value (in 2007 dollars) of the stock of carbon under each scenario and measure the change in value between the base future climate carbon stock and the stock estimated under each scenario.

For this study, we draw upon the literature to provide best estimates of the 2007 market price of carbon per metric ton to estimate the market value of carbon sequestered or released. In addition to estimates based on the market value of carbon, we use the literature to provide a review and best estimates of the societal value of a ton of carbon sequestered (or the costs of a ton of carbon released), recognizing that the value of carbon sequestered also will change over time, mostly as a function of the total stock of carbon in the atmosphere and the time of release or sequestration.

To estimate the value of carbon stored, we valued the costs of carbon emitted, assuming that if the carbon stock at time *t* decreases by one ton of carbon, that ton has (1) a market impact because it will need to be offset in the carbon market,[2] and (2) an economic impact because it causes a marginal increase in damages associated with climate change.

Market Value of Carbon
We use information from the Chicago Climate Exchange (CCX, a voluntary climate exchange) and the European Union Emissions Trading System (EU ETS), a compliance-based system to estimate market values. To meet the goals of AB32 and reduce the impacts of atmospheric carbon on the global climate, The California Air Resources Board (CARB) has recommended a cap-and-trade program. Forest carbon offsets (aboveground live biomass in trees) are to be included in the program as a limited percentage of allowances. A cap-and-trade program will create a market for carbon and carbon sequestered by forests could be used to offset carbon generated by industry. The actual market value of forest carbon will depend on the development of this program and specific allowances made for forest carbon offsets. Generally, the market price is determined by the total amount of carbon that is permitted to be released into the atmosphere and the cost of meeting this cap through reductions in carbon emissions or the sequestration of carbon (for instance in natural vegetation.) From the perspective of the State of California, carbon sequestration is an important part of the technical portfolio the state must employ in order to meet the goals of AB32. Market price provides a rough estimate of the potential costs of meeting these goals and thus the gross economic value, in terms of cost savings or increases that would result due to changes in the natural ability of terrestrial ecosystems to sequester carbon. (Note, marine systems also play an important role in carbon sequestration, but we do not currently have good quantitative models for marine CO_2 sequestration.)

Currently, carbon trading occurs through a number of allowance-based markets and project-based transactions. The three main markets are the European Union Emissions Trading Scheme (EU ETS) and the New South Whales GHG Reduction Scheme, which are both regulated markets, and the CCX. For this study, we use 2007 annual volumes and transactions on the EU ETS and CCX markets to derive a low and high price for a metric ton of carbon. For each market, we derive the average annual price per metric ton of carbon (MTC) as follows:

$$\left(\frac{Total\ Value\ (M\$)}{Total\ Volume\ (MtCO_2e)} \right) 3.67$$

where 3.67 is the conversion factor from CO_2 to carbon.

The price derived from the EU ETS is \$89.19/MTC and from CCX is \$11.49/MTC (Capoor et al. 2008). The reason for the large difference in price between the CCX and the EU ETS markets is that the EU ETS is a regulated cap-and-trade market. In a regulated market, buyers have a higher certainty that what they are buying will maintain a value in the market. The CCX is a voluntary market with higher levels of uncertainty. Buyers speculate that the credits they

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[2] The AB 32 (Assembly Bill 32 - California's Global Warming Solution Act of 2006) Climate Change Scoping Plan, approved by the Air Resources Board on December 11, 2008, recommends developing a cap and trade program that would link with other Western Climate Initiative partner programs to create a regional market by 2012. The plan recommends reduction measures of 5 MMTCO2e in the sustainable forest sector. It also recommends the use of offsets (include in the forest sector) and allowances from other systems be limited to 49 percent of the required reduction of emissions.

purchase will hold value should a cap-and-trade system be developed. Investors are looking for high potential returns on their investments given the risk they incur.

The CCX price could be considered a lower bound value (should forest offsets not be included in a regulated market). The EU ETS rate could be considered a more accurate estimate if forest carbon offsets are included in a statewide, regional, or national cap-and-trade system.[3]

Social Value of Carbon
The economic value of carbon sequestration can also be measured in terms of the social cost (or economic benefit from avoided damage) of damage avoided when carbon is removed from the atmosphere and climate change is slowed. The social cost of carbon (SCC) measures the full global cost today of emitting an incremental unit of carbon (in the form of CO_2) at some point of time in the future, and it includes the sum of the global cost of the damage it imposes the entire time it is in the atmosphere (Price et al. 2007; Pearce 2003). Damage is a function of the cumulated stock, so one extra unit released in the future is likely to have a higher associated damage than a unit emitted now (Pearce 2003). In theory, the SCC attempts to capture how much society could pay to avoid climate change and still be as well off as they would be in the absence of climate change. In other words, if society were aware of the full costs of climate change, the SCC is what they would be willing to pay now to avoid the future damage caused by incremental carbon emissions (Price et al. 2007). The SCC also represents the appropriate tax on CO_2 emissions that would result in the economically optimal reduction in CO_2 emissions (also known as the Pigouvian tax—a tax levied to correct the negative externalities of a market activity) (Tol 2007). The total social cost is the damage done by carbon emissions compared to a neutral climate future context in which the emissions do not increase. In our analysis, we assume that lost carbon sequestration is not offset by technological reductions in human-created sources of atmospheric carbon dioxide and thus lost carbon sequestration results in global economic cost.

The process for estimating SCC requires a model of atmospheric residence time and a means of discounting economic values back to the year of emissions (Yohe et al. 2007). The amount of damage done by each incremental unit of carbon in the atmosphere depends on the concentration of atmospheric carbon today and in the future. Therefore, the SCC should vary depending on which emissions trajectory the world experiences.

Currently, the peer-reviewed and gray literature provide over 200 different estimates of the marginal costs of climate change with varying levels of sophistication, including differing discount rates, different mechanisms for including discount rates and performing sensitivity analysis, varying estimates of total costs of climate change used, dynamic and static elements, differing assumptions about future climate change, and publication dates (the older the study, the less sophisticated it might be) (Tol 2007). Generally, a higher discount rate implies a lower estimate of the SCC and estimates in the peer reviewed literature tend to be lower than estimates in the gray literature and have fewer uncertainties (Tol 2007).

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[3] Note that forest sector offsets are not included in the EU ETS compliance system, but this system still provides the best market estimate for forest sector carbon credits. Also note that the California AB 32 Climate Change Scoping Plan recommended inclusion of forest credits produced in-state, as well as out-of-state and internationally, although the rules for these mechanisms have yet to be created.

In 2005, Richard Tol published a meta-analysis of the marginal damage costs of CO_2 emissions. He reviewed 103 estimates from 28 public studies. Including only peer-reviewed studies and accounting for differences in the types of studies (discount rates, equity weighting, dependence on dynamic climate change scenarios and economic scenarios, and estimations of marginal or average damage costs), Tol determined the mean to be \$43 (\$54 in 2007 inflation adjusted dollars) per MTC with a standard deviation of \$83 (Tol 2005). He found that studies with better methods yielded lower estimates with fewer uncertainties. He also discovered that much of the uncertainty was due to assumptions on the discount rate and around equity weights used to aggregate monetized impacts over countries.

In 2007, Tol presented an as yet unpublished update of his 2005 meta-analysis. With more data (211 estimates from the gray and published literature) and more advanced statistical analysis, Tol's results showed a downward trend in the estimates of the SCC but that uncertainty about the SCC is large (although many of the high estimates were not yet peer-reviewed and used unacceptably low discount rates). In Tol's 2007 analysis, with conservative assumptions, the mean for peer-reviewed estimates is \$23/MTC. He states that there is a 1% probability that the SCC is greater than \$78/MTC.

Watkiss and Downing (2008) provide further updates of Tol and summarize a number of values for the social cost of capital for carbon emissions in the UK. The authors report that in 2002, the UK Government recommended a marginal global SCC estimate of £70/MTC (\$185/MTC in 2007 dollars), within a range of £35 to £140/MTC (\$93 to \$371/MTC in year 2007 dollars), with all three estimates increasing £1/MTC (\$1.50/MTC) per year from the year 2000. Since 2002, the UK Government has used these values widely in regulatory impact assessment and for considering environmental taxes and charges (Watkiss et al. 2008). We conservatively examine a central value from Watkiss and Downing of \$185/MTC (2007 dollars) noting that the authors expect significant increases over time. (The authors also provide estimates from the FUND and PAGE models, which are substantially higher than even the UK SCC estimates.)

Using the DICE-2007 model, William Nordhaus shows that the trajectory of optimal carbon prices (or carbon taxes) should rise to reflect the increasing damage caused by climate change and the need for increasingly tight constraints. In the model, the optimal price rises steadily over time, at between 2% and 3% per year in real terms, to reflect the rising damages from climate change. In this trajectory, Nordhaus' carbon price (adjusted to 2007 dollars) rises from \$34/MTC to \$113/MTC by 2050 and \$251 per MTC in 2100. Ultimately, the carbon price will top out at the level at which the backstop technology becomes economically viable (Nordhaus 2008).

The DICE-2007 model is a globally aggregated model. The model incorporates simplified representations of the major analytical dimensions of climate change problems and is focused on analyzing the economic and environmental impacts of alternative policies (Nordhaus 2008). Like the other models, DICE-2007 does not provide for a complete understanding of the major components and has greater error the further into the future the projections move. It contains highly simplified representations of the major relationships relating emissions, concentrations, climate change, the costs of emissions reductions, and the impacts of climate change, and some of the tradeoffs—particularly between rich and poor regions—cannot be explored (Nordhaus 2008).

Realizing that no model is perfect, that each method for estimating the SCC or optimal carbon price provides different perspectives, and that there are complexities and uncertainties relating to how different variables are considered in the models, we use Nordhaus' carbon price trajectory to illustrate the potential costs (and benefits) to society that climate change can have as a result of changes in forest carbon stocks in California. (Note that as mentioned previously, social cost values have been discounted)

Predicting the Value of Future Carbon Sequestration

As the aboveground carbon storage varies, there is subsequent variation in total market value represented by losses or gains in natural carbon sequestration in the future (Table 2a). With the warmer and wetter climate (PCM1), the change in market value is positive, ranging from an average annual difference due to climate change of $19 million to $146 million/year for 2005–2035 under scenario B1 to as much as $1 billion to $7.9 billion annually by 2065–2090. The warm, wet PCM1 climate simulations consistently enhance carbon sequestration for all the periods considered and thus increase the service value, with highest change at the end of the century (2065–2099) under the low emissions scenario (B1). Conversely, under the high (A2) emissions scenario, climate projections by the hot, dry CCSM3 model cause an average annual loss of between $2.9 billion and $22.1 billion.

These estimates for changes in market values are in 2007 dollars with no discounting for present value. It is conceivable that in a market situation, real market prices will change—prices could increase if it becomes more expensive to reduce greenhouse gas emissions and, conversely, technological innovation could cause market prices to fall. Market prices will also vary depending on the types of policies implemented at the state and national level. Research economists from New Carbon Finance predict that if a cap-and-trade program is confined to domestic trading only, the carbon emissions market could be worth $1 trillion by 2020 (Environmental Leader 2008). Allowing trading with other countries like India or China, where emissions reduction measures are relatively inexpensive will yield lower prices and a cost savings to the U.S. economy (New Carbon Finance 2008).

Table 2a. Projected change in live aboveground carbon sequestered and the market value of these changes

2005–2034					
		Carbon		Change in value (2007$ million)	
Scenario	Model	Total (Tg)	% Change from Base	CCX $3.13/MTCO2e ($11.49/MTC)	EU ETS $24.30/MTCO2e ($89.20/MTC)
Base		*1,025*			
B1	PCM1	1,027	0%	$19	$146
	GFDL	997	-3%	-$325	-$2,524
	CCSM3	997	-3%	-$323	-$2,504
A2	PCM1	1,035	1%	$115	$891
	GFDL	1,024	0%	-$15	-$118
	CCSM3	992	-3%	-$380	-$2,950

2035–2064					
		Carbon		Change in value (2007$ million)	
Scenario	Model	Total (Tg)	% Change from Base	CCX $3.13/MTCO2e ($11.49/MTC)	EU ETS $24.30/MTCO2e ($89.20/MTC)
Base		*1,028*			
B1	PCM1	1,057	3%	$327	$2,541
	GFDL	987	-4%	-$475	-$3,685
	CCSM3	881	-14%	-$1,693	-$13,145
A2	PCM1	1,055	3%	$304	$2,357
	GFDL	968	-6%	-$690	-$5,355
	CCSM3	902	-12%	-$1,446	-$11,223

2070–2099					
		Carbon		Change in value (2007$ million)	
Scenario	Model	Total (Tg)	% Change from Base	CCX $3.13/MTCO2e ($11.49/MTC)	EU ETS $24.30/MTCO2e ($89.20/MTC)
Base		*952*			
B1	PCM1	1,041	9%	$1,021	$7,926
	GFDL	935	-2%	-$199	-$1,546
	CCSM3	820	-14%	-$1,516	-$11,769
A2	PCM1	1,023	7%	$815	$6,327
	GFDL	778	-18%	-$1,994	-$15,481
	CCSM3	704	-26%	-$2,850	-$22,129

Table 2b. Projected change in live aboveground carbon sequestered and the economic value including social cost of carbon of these changes

2005–2034						
		Carbon		Change in value (2007$ million)		
Scenario	Model	Total (Tg)	% Change from Base	Tol, 2007 Mean ($23/MTC)	DICE-2007 Optimal Price ($34/MTC)	Existing UK SCC ($185/MTC)
Base		*1,025*				
B1	PCM1	1,027	0%	$38	$56	$303
	GFDL	997	-3%	-$651	-$962	-$5,236
	CCSM3	997	-3%	-$646	-$955	-$5,194
A2	PCM1	1,035	1%	$230	$340	$1,847
	GFDL	1,024	0%	-$31	-$45	-$245
	CCSM3	992	-3%	-$761	-$1,125	-$6,119

2035–2064						
		Carbon		Change in value (2007$ million)		
Scenario	Model	Total (Tg)	% Change from Base	Tol, 2007 Mean ($23/MTC)	DICE-2007 Optimal Price ($113/MTC)	Existing UK SCC ($185/MTC)
Base		*1,028*				
B1	PCM1	1,057	3%	$655	$3,220	$5,271
	GFDL	987	-4%	-$950	-$4,669	-$7,644
	CCSM3	881	-14%	-$3,390	-$16,656	-$27,269
A2	PCM1	1,055	3%	$608	$2,987	$4,890
	GFDL	968	-6%	-$1,381	-$6,786	-$11,109
	CCSM3	902	-12%	-$2,894	-$14,220	-$23,281

2070–2099						
		Carbon		Change in value (2007$ million)		
Scenario	Model	Total (Tg)	% Change from Base	Tol, 2007 Mean ($23/MTC)	DICE-2007 Optimal Price ($251/MTC)	Existing UK SCC ($185/MTC)
Base		*952*				
B1	PCM1	1,041	9%	$2,044	$22,309	$16,443
	GFDL	935	-2%	-$399	-$4,350	-$3,207
	CCSM3	820	-14%	-$3,035	-$33,123	-$24,413
A2	PCM1	1,023	7%	$1,632	$17,807	$13,125
	GFDL	778	-18%	-$3,992	-$43,570	-$32,113
	CCSM3	704	-26%	-$5,707	-$62,281	-$45,904

The expected change in the social value of stored carbon (Table 2b) is similar to that found for the analysis of market values. The warm, wet PCM1 model consistently predicts a higher capacity to store carbon and thus the affect of climate change on natural carbon storage in

California would result in a net benefit to society of between of $38 million annually in the period 2005–2034 and as high as $22 billion annually by 2070. The hotter, drier models, however, project a sharp negative difference in carbon storage capacity in natural areas leading to social costs of -$646 million to -$5.2 billion annually for the period 2005–2034 (under scenario B1 using the CCSM3 model of climate change) to as high as -$62 billion annually by the period 2070–2099, under scenario A2 using the Nordhaus' DICE-2007 model predictions.

Conclusion: Carbon Sequestration

The current voluntary carbon markets that incorporate natural system sequestration focus largely on the aboveground biomass in a forest system and so, for this study, we focused our valuation on aboveground biomass in forested systems. Sequestration of aboveground biomass decreases with all model-emissions scenario combination except the most optimistic, and the declines are more pronounced in the second and third time periods of this study. There are two main reasons why the model projects a decline in biomass: (1) loss of conifer forests due to drought stress, which might be mitigated to some extent by a CO_2 "fertilization effect" that may enhance carbon capture as CO_2 concentrations increase but more importantly should increase water use efficiency—that is, maintaining carbon uptake under a moderate level of drought stress; (2) fire losses will be significant as temperatures rise and humidity drops. When all carbon stocks (i.e., aboveground and belowground live biomass, aboveground and belowground organic carbon) are included in the analysis—not just the aboveground biomass carbon stocks included in the existing voluntary carbon market—the picture changes slightly. Net change in total carbon stocks increases under the warmer, wetter future (PCM1) for both the low and high emissions scenarios (Appendix B). In contrast, we see decreased carbon storage under both emissions scenarios using the hot, dry models (GFDL, CCSM3), largely driven by a combination of decreases in aboveground and belowground organic carbon (Appendix B). In the model-emissions scenarios with carbon loss, fires burn the vegetation and carbon losses are emitted as gases and drought conditions reduce production and carbon capture, resulting in total carbon loss. For California to take advantage of the potential for carbon storage in natural systems stocks in the future, greenhouse gas emissions must be curbed to a B1 scenario that would reduce both drought-stress conditions for natural and commercial vegetation (forests, agriculture, forage) and fire danger.

The results of our carbon projections indicate that forests and other sources of natural carbon storage are critically important assets that need to be considered, employed, and protected if we are going to work to stem the increase in global atmospheric concentration of carbon dioxide. The majority of the model-emissions scenarios find that climate change will lead to a loss of the natural ability of California's forests to store carbon by the end of the century. The result will be annual losses of potentially hundreds of millions and possibly billions of dollars in carbon sequestration capacity—a cost that will be borne by carbon emitters, automobile drivers, factories, homeowners, and others—and will be reflected in future markets for carbon. Similarly, this loss of carbon sequestering capability will result in global economic impacts if the loss of carbon is not offset by other reductions in carbon emissions.

Forage Production

Forage production is a provisioning service in the grasslands and woodlands of California that supports both native herbivores and domestic livestock. Under appropriate management grazing enhances biodiversity and limits invasion by aggressive exotics plants in California grasslands (Marty 2005). Ranching as an economic enterprise is critical to maintaining habitat for many species throughout the rangelands of California, especially in areas undergoing rapid fragmentation such as the Sierra Nevada foothills. The quality and abundance of forage available at a particular site varies year to year and is strongly correlated with the rainfall and the length of the growing season (George et al. 2001). Soil characteristics (fertility, pH, available water content) also influence forage production, with many of the most productive soils already subject to agricultural and urban land use conversion. Additionally, the management of residual dry matter can affect rangeland productivity (George et al. 2001).

Forage Production Modeling

We analyze the projected changes in distribution and production of forage within grassland and oak woodland habitat under future climate scenarios using monthly precipitation data from two AOGCMs (GFDL, PCM1) for each emissions scenario (low, B1 and high, A2), the projected vegetation output from MC1, and the Natural Resources Conservation Service (NRCS) State Soil Geographic (STATSGO) soil data.

Soil Data

Estimates of annual dry matter forage are available for much of the state’s rangelands for favorable, unfavorable, and average years through the STATSGO soil database (NRCS 1994). The STATSGO dataset is organized based on basic soil characteristic *components,* including forage production. Not all rangeland in the state had forage production estimates available (as defined by the *rsprod_r* component), particularly in the northern Sacramento Valley. To assign average production estimates to map units missing values, we used the average forage production values of the components within those map units. We weighted the average production values by the percentage of the map unit in that component (as defined by the *comppct_r* field). We assigned a value to a map unit only if the production values were available for components that collectively covered at least 20% of the map unit. We then used the average monthly precipitation from 1971–2000 at 400 meter resolution (available from PRISM, Daly et al. 1994) to calculate the amount of forage produced by month per unit of precipitation, as shown in Equation 1. Because the timing of precipitation greatly affects the forage production, we used the growth curve for representative rangeland sites available through the NRCS Ecological Site Description website (http://esis.sc.egov.usda.gov) to proportionally allocate the annual range production into growing season months. Table 3 shows the percentage of the annual forage production at a site allocated by month. We generated six monthly production grids, one for each month of the growing season by multiplying the annual sum production grid (as mapped using *rsprod_r* values) by the percentage of the annual growth in that month. These grids were divided by the historical average monthly precipitation to derive the production per unit of precipitation for each month. These grids were upscaled from 400 m resolution to the 12 km grid cells used in this project using the zonal mean function in ArcGIS (ESRI 2006).

Equation 1. Formula to estimate monthly forage production / precipitation relationship for grid cell x

$$MonthlyForagePerPrecipitation_x = \frac{(Forage_{ann} * ProductivityPct_{monthly})}{Precipitation_{monthly}}$$

Table 3. Monthly forage production for majority of rangeland sites in California (% of annual lbs per acre)

Month	November	December	January	February	March	April	May
% of annual production in lbs per acre	10	10	0	10	25	40	5

We used the average monthly precipitation values for each grid cell for the historical, neutral climate future, and three future scenario time periods to generate the estimates of production by multiplying the precipitation value with the respective monthly grid of production per unit of precipitation (as calculated in Eq. 1). We summed the resultant monthly production across the six growing season months to generate the annual production for each cell (in pounds per acre.) To integrate the projected vegetation distribution into future estimates of range production, we only included cells in either herbaceous or hardwood woodland land cover as projected by MC1 in the estimates of range production. Finally, to account for current and projected anthropogenic land cover, we multiplied the annual production value for each grid by the percentage of each grid cell not in either agriculture or urban for each time period as described in the carbon sequestration section. Our approach does not account for the role of temperature in influencing the length of the growing season. This is potentially an important factor in the total forage produced in a given area (George et al. 2001), but there is considerable variation across the state in terms of whether it is fall or spring temperatures that affect productivity. In addition, the need for high temporal resolution data to calculate degree days to use in a model of production was beyond the scope of this project. As such, our approach may overestimate the influence of precipitation relative to temperature in affecting forage production. With expected warming, it is likely to expect increases in grass net primary production which could mitigate the decline in productivity due to decreases in precipitation or drought stress.

Additional Considerations

The quality (i.e., nutrient content) of the forage itself is also an important factor that would ideally be included in a determination of the livestock carrying capacity of a parcel of land (George and Bell 2001). The determinants of carrying capacity for livestock is due to more than just the dry matter produced—comparative nutrient provision of various plants play an important role (George et al. 2001a). Additionally, there are various nutritional requirements for different stages in a cow's life. Ideally the lands are managed such that they meet these requirements and match the lifecycles and reproductive patterns of livestock (George et al. 2001a; George et al. 2001b). Modeling the nutrient content of the forage produced is beyond the scope of this project, but it is still important to note its role. Other factors that affect the carrying capacity of rangelands for livestock such as management costs, topography and adjacent land ownership are beyond the scope of this assessment.

Projection of Future Forage Production

Forage production declines dramatically by the end of the century (2070–2099) in all future projections, ranging from a 14% decline in annual mean (Tg) production under the PCM1-B1 scenario to a 58% decline under the GFDL-A2 scenario (Table 4).

Table 4. Absolute and percent changes in forage production (Tg) from the neutral climate future and changes in forage production value under low and high scenarios for two AOGCMs (PCM1 and GFDL) across three time periods in the future

2005–2034					
Scenario	Model	Forage		Difference in Value ($ million)	
		Total (Tg)	% Change from Base	Profits from Livestock	Cost of Replacement for Hay
Base		13.00			
	PCM1	11.90	-8%	-$14	-$47
B1	**GFDL**	8.54	-34%	-$57	-$192
	PCM1	14.19	9%	$15	$51
A2	**GFDL**	10.14	-22%	-$36	-$123

2035–2064					
Scenario	Model	Forage		Difference in Value ($ million)	
		Total (Tg)	% Change from Base	Profits from Livestock	Cost of Replacement for Hay
Base		12.24			
	PCM1	11.65	-5%	-$8	-$25
B1	**GFDL**	8.28	-32%	-$50	-$170
	PCM1	11.63	-5%	-$8	-$26
A2	**GFDL**	7.39	-40%	-$62	-$209

2070–2099					
Scenario	Model	Forage		Difference in Value ($ million)	
		Total (Tg)	% Change from Base	Profits from Livestock	Cost of Replacement for Hay
Base		12.52			
	PCM1	10.79	-14%	-$22	-$74
B1	**GFDL**	7.05	-44%	-$70	-$235
	PCM1	8.56	-32%	-$50	-$170
A2	**GFDL**	5.26	-58%	-$92	-$312

The forage production declines are smaller in low emissions scenario (B1) relative to the high emissions scenario, decreasing from 14% under the warm, wet PCM1 model and 44% under the hot, dry GFDL model in the last time period in the twenty-first century (Table 4 and Figure 13), In contrast, the high emissions scenario (A2) causes much steeper declines, ranging from -32% and -58% for under the PCM1 and GFDL models, respectively (Figure 13). These changes are due primarily to the decreases in rainfall amounts, especially under the GFDL model, that drive declines in the extent of the herbaceous rangeland cover type that dominates the grassland/rangeland areas including grasslands and hardwood woodlands.

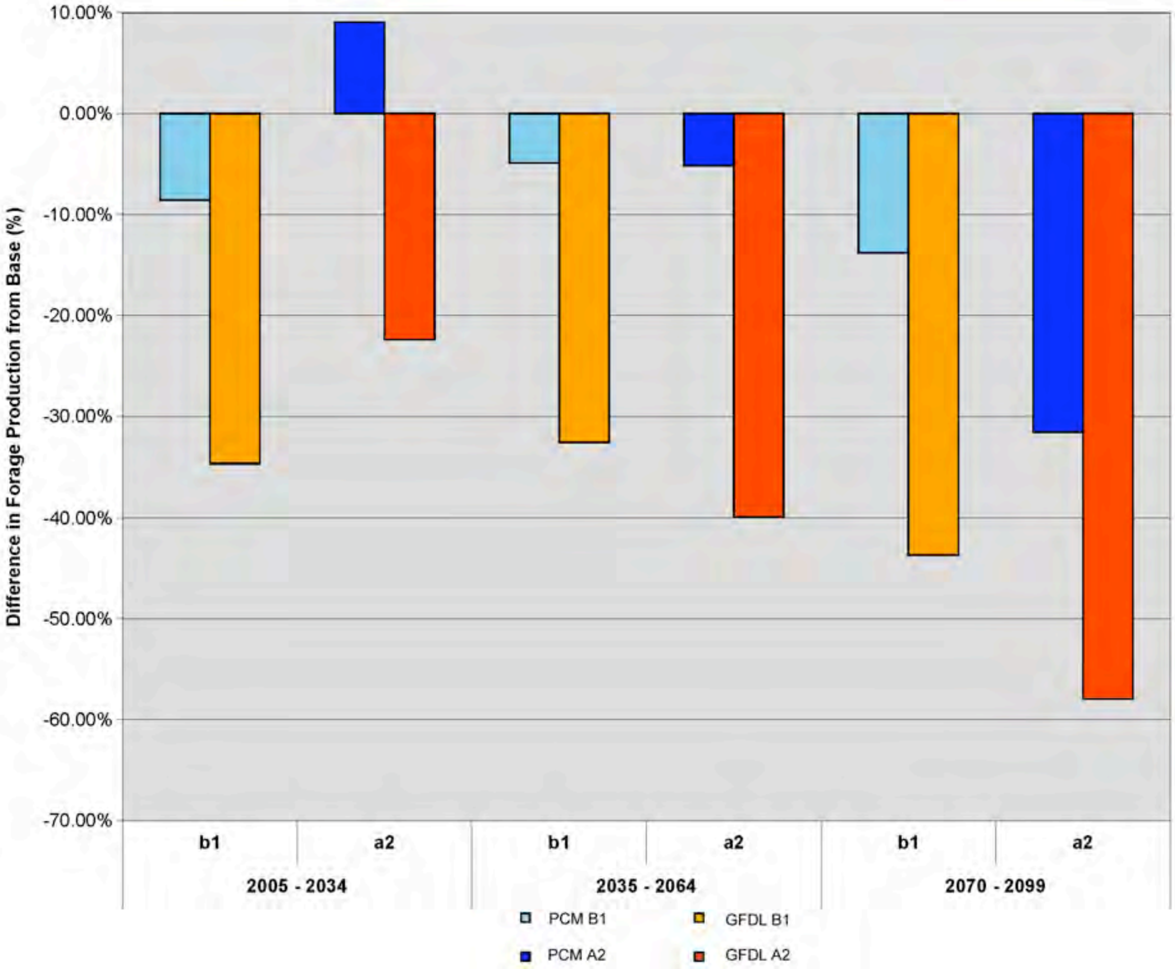

Figure 13. Percent change in forage production compared to the historical period across three time periods under each AOGCM-emissions scenario combination

In projections using the hotter, drier GFDL model, the pattern of decline in rangeland extent is similar to declines in forage production, with increasingly larger declines towards the end of the century using both the PCM1 and the GFDL models (Figures 13 and 14). In contrast, the warmer, wetter model increases rangeland extent (Figure 14) even as production decreases toward the end of the century (Figure 13). By the end of the century using the hotter, drier model (GFDL), rangeland extent is projected to decrease by 20% and 23% while forage production is projected to decrease by 44% and 58%, under the low (B1) and high (A2) emissions scenarios, respectively (Figure 13, Table 4). By the end of the century using the warmer, wetter scenario (PCM1), rangeland extent is projected to increase 7% under the B1 scenario and decrease almost 6% under the A2 scenario, while forage production is projected to decrease by 14% and 32%, under the B1 and A2 scenarios respectively (Figure 13, Table 4). Only under the PCM1-A2 is there a net increase in forage production. That increase has occurred by the first time period (2005–2034), but it is followed by a pronounced drop by the end of the century. The urban growth expansion contributes to the decline in rangeland extent, especially in more productive, lower-elevation regions of the state. This influence is minimal, however, compared to the climate-induced changes.

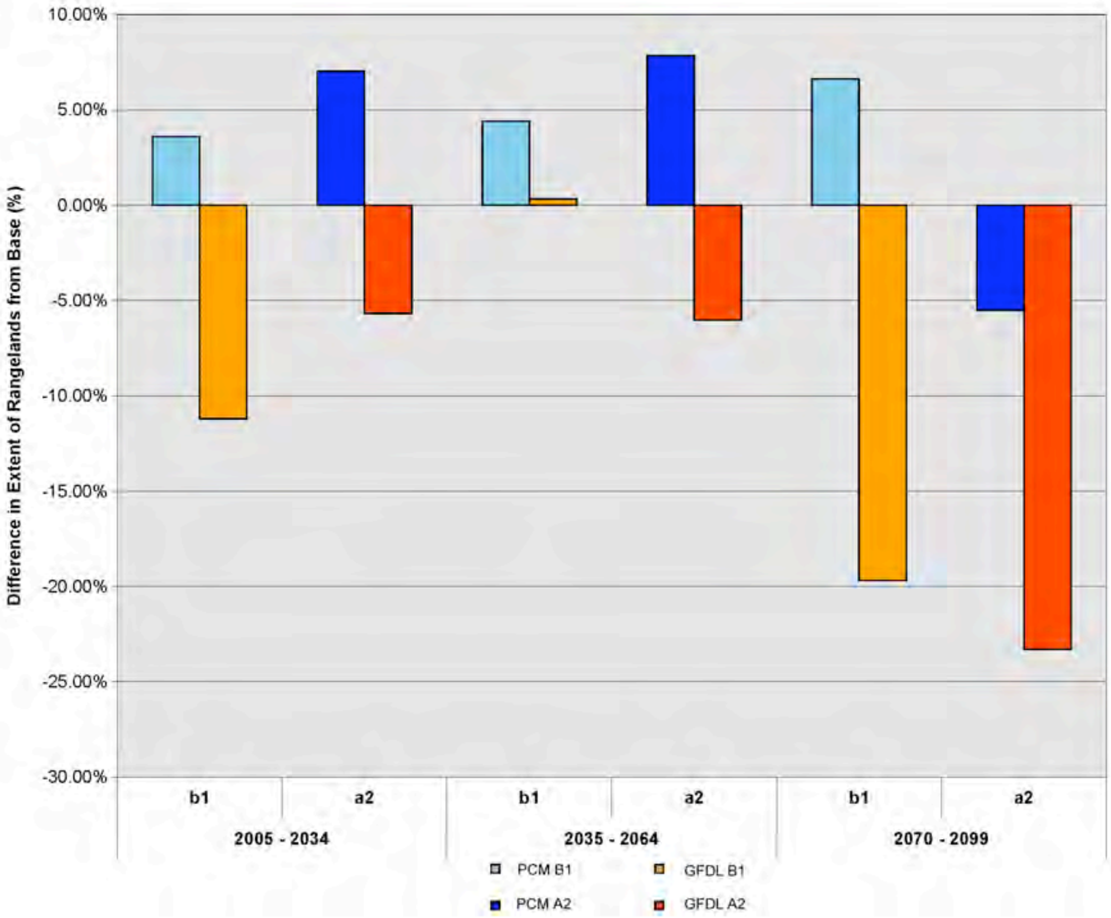

Figure 14. Percent changes rangeland extent (vegetation types grassland and hardwood woodland) compared to historical conditions across three time periods under each AOGCM-emissions scenario combination

The geographic pattern of the changes in forage production projected by the end of century (2070–2099) differs dramatically among AOGCMs and emissions scenarios (Figures 15 and 16). Many of the largest declines in forage production are due to conversion of rangeland in highly suitable climates. The spatial pattern of change in forage production with the PCM1 model under both B1 and A2 scenarios is heterogeneous with highly interspersed areas of positive and negative changes, especially in the central Sierra and inner North Coast suggesting that this pattern is explained by shifting vegetation types, more than a strong regional climate trend. The regional pattern for the AOGCM generally shows an increase in production in the northern part of the state and a drop in the inner Central Coast and Sierra foothills. In contrast, using the drier and warmer GFDL climate under both B1 and A2 scenarios causes extensive declines in production with large declines concentrated in the inner Central Coast region and along the Sierra Nevada foothills. The hottest and driest scenario/model combination, GFDL-A2, projects extensive and consistent declines in production over virtually all of the current extent of rangelands, with only minor increases in the inner North Coast, Sacramento Valley, along the South Coast and at higher elevations in the Sierra Nevada.

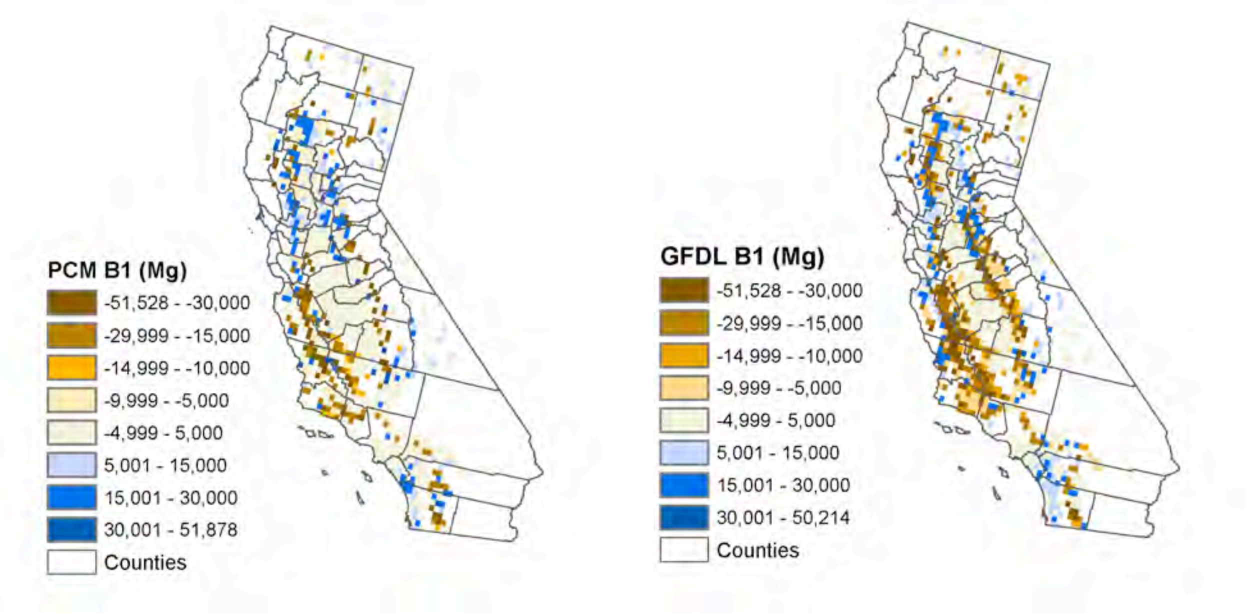

Figure 15. Net change in forage production in 2070–2099, under the low B1 emissions scenario between the neutral climate future scenario and two AOGCMs (PCM1 and GFDL) simulated future climate conditions. Areas in the dark brown represent a decline in forage production, while those in the dark blue represent an increase in forage production.

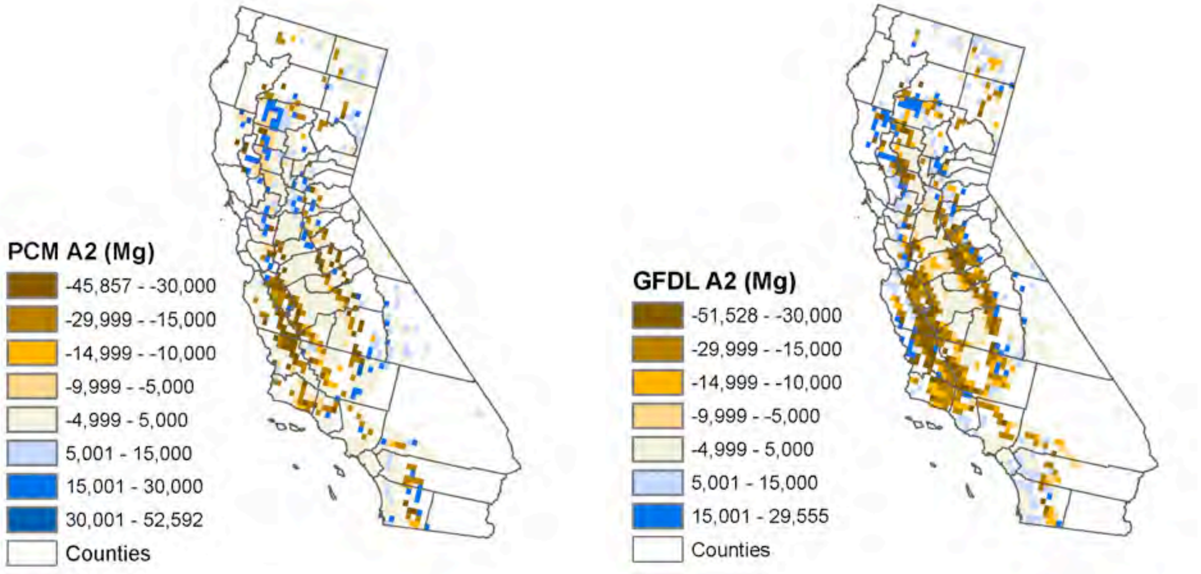

Figure 16. Net change in forage production in 2070–2099, under the low A2 emissions scenario between the neutral climate future scenario and two AOGCMs (PCM1 and GFDL) simulated future climate conditions. Areas in the dark brown represent a decline in forage production, while those in the dark blue represent an increase in forage production.

Forage Valuation

Climate change could substantially change land cover, including how much land is available for grazing livestock. Grazing lands provide plant material for livestock feed. This function can be considered an ecosystem service because management inputs to grazing land are minimal. The service provided by nature is the production of forage. Putting a value on forage production helps us to understand the benefits associated with the service (or the costs of not having the service).

Forage generates both economic value (by creating profit for cattle ranchers and additional values for rangelands) and economic impact (forage production indirectly generates jobs, wages, and taxes). For the purposes of this study, we examine the economic value of forage as it relates to its function as an input to the livestock market. To avoid "double-counting" in our analysis, we separate landscape from forage production as two distinct components to be considered in the value of grazing lands. We do not value quality of life,[4] landscape, or fire and

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[4] In some of the literature, it is argued that grazing landscapes have measurable impacts on quality of life, and that these values also should be measured (Bartlett et al. 2002). Ranchers and even non-ranchers have a willingness to pay (WTP) for grazing lands that is not based purely on the economic benefit they receive from the cattle business (Torell, 2001). Livestock's historical, exceptionally low average 2% rate of return (Workman 1986; Bartlett et al. 2002) and the high ranking that quality of life plays in ranchers' decisions to buy grazing lands is often quoted as evidence of this WTP. Hedonic pricing and contingent valuation studies have attempted to capture this value (Hof et al. 1989; Bartlett et al. 2002). Cultural and aesthetic values like these are an important part of ecosystem service valuation and should not be ignored. However, the willingness-to-pay in these cases applies more to the open land and not exclusively to the

invasive species management on grazing lands nor do we attempt to calculate what, if any, additional costs to society would be created by changes in greenhouse gases caused by more or fewer head of cattle.

We consider the final service (or end product) of forage production to be livestock. We identify the following two mechanisms for valuing forage production: (1) the market in livestock and its products (see Chan et al. 2006); and (2) the price of the least cost replacement (substitute) for forage as a livestock feed. In a free market, grazing fees also could be considered as a reflection of the market's valuation of the contribution of grazing land and forage to the production beef. We do not consider grazing lease fees because in California, close to 50% of grazing leases are on public lands and reserves (primarily Bureau of Land Management (BLM) or Forest Services land (FRAP 2003). BLM grazing lease rates are set by the federal government and are not sensitive to market forces. In fact they are heavily influenced by non-market factors and therefore are not useful as a true reflection of the costs and benefits of forage production (Agee 1972; Torrell 2001; Bartlett 2002; LaFrance et al. 2003). Private lease rates throughout the west have been shown to vary widely and fail to correlate predictably or accurately to the value of forage on grazing lands (Adkins and Graeber 1978; Van Tassell et al. 1997). Thus, lease rates are unlikely to be an accurate means of directly estimating the marginal value of forage unless we are able to accurately model the hedonic aspects of grazing lease values—something that has not been done to date.

In our model, each 12 km x 12 km cell of rangeland generates associated forage dry matter (DM) in units of annual tons, which in turn supports livestock production. We assume that only 50% of forage produced on an acre of land is available for livestock production; the rest must be used for management of land productivity, or it is lost due to trampling and contamination from animal waste. We measure animal production from forage as an Animal Unit Month (AUM), which is defined as the amount of DM necessary to sustain a 1,000 pound cow and her calf for a month. A recent study prepared for the California Energy Commission reports that an average of 791 pounds of DM is equivalent to one AUM (Brown et al. 2004). This is supported by a study conducted in Hawaii that reports a similar result (Thorne et al. 2007).

Market Value of Livestock

The market value of livestock (livestock profits per AUM) provides us with a lower bound estimate for the economic value of forage production. There are no precise estimates of the marginal product of forage in cattle production (i.e., how many more pounds of beef are produced by one more unit of forage), so we follow Brown et al. (2004) to estimate the average value of a ton of forage by looking at livestock profits per AUM.

Brown et al. (2004) consider costs and revenues on ranches in each county in California. They report the following breakdowns as a statewide average. Values are adjusted for inflation to year 2007:

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production of forage. Additionally, these values might only be relevant to small-scale ranchers. For large-scale landowners, cattle ranching may have other, hidden benefits, such as tax advantages, but not the same quality of life value.

Average per cow profitability:	$110.00
Annual average per cow forage DM requirements:	9,492 lbs (given 791 AUM)
Each pound of DM:	$0.011553 in profit

We calculate the economic value of forage change (measured as DM) by first halving the total forage production predicted by our forage lands model to account for the amount of forage available for livestock production. We then multiply the change in DM by its value as measured through average state livestock prices ($0.011553 per pound of DM). Limitations of this methodology include (1) broad assumptions that nutrient and protein content of forage across landscapes are constant, (2) failure to account for seasonal variety in animal requirements, (3) failure to reflect regional variation in the value of livestock due to quality, market factors, and access and distance to markets,[5] and (4) not accounting for the carrying capacity of the lands (a rise in prices for beef and/or a decrease in non-feed costs would most likely increase returns per pound of DM and therefore increase the optimum stocking rate for cattle.)

Table 5. Revenue and costs associated with cattle ranching in California (in 2003 $).
Figures are adjusted for inflation to year 2007 $.

Revenue			
	Total	$/cow	Assumptions
Calf	$812.00	$690.00	85% wean rate
Cull cows	$731.00	$110.00	15% cull rate
Total Revenue		$800.00	
Costs in $/cow			
Pasture		$180.00 (including cost for bulls – 5% of herd)	
Supplemental feed		$236.00 (including replacement heifers – 15%)	
Other operating & fixed costs		$274.00	
Total Costs		$690.00	
Mean Annual Profit per Cow (Revenue – Costs)		$110.00	

Adapted from Brown et al. (2004).

Replacement Cost of Forage

As an upper bound for the potential value of forage, we also consider its replacement cost at the margin. As a proxy for lost forage, we recognize that ranchers feed their livestock hay during periods of low forage productivity. Following this logic, we assume that a low grade hay variety, in this case the lowest grade hay available from each county in California in 2003 (USDA 2004), is a roughly equivalent substitute (at the margin) for forage. We use the market price averaged across all counties in California that provide the same hay type (USDA 2008) to calculate a maximum bound for the potential change in value of forage production resulting from climate change. In this case, no conversion to AUM is necessary. We assume that forage

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[5] Ideally, we would capture regional differences using the state data as a neutral climate future and adjusting costs per cow (lease fees, supplemental feed, and operating costs) and revenue (given county livestock price data), yielding different profits for each pound of forage in a given county in California. However, insufficient county-level data are available to accurately include them in this report, so a state average is used.

and hay are equally nutritious on a one-to-one basis and so a simple, direct cost of replacement is calculated on a pound-by-pound—forage for hay—basis, yielding a value of approximately $78/ton.

The economic cost of hay is roughly ten times the economic value of natural forage in terms of increased profit from one ton of natural forage. More research would be needed to determine exactly what types of feedstock could be substituted for natural forage. Discrepancies could arise with this option as the hay market is not necessarily directly tied to the livestock market and includes other uses for hay in its price. Further, the future real market price of hay could change due to a number of other factors.

Predicting the Value of Future Forage Production

The vast majority of the 100 million head of cattle and 6 million head of sheep in the United States depend on forage grasses at some point in the production cycle (Pons 2005). The USDA estimates a total cattle count of approximately 5.5 million cattle in 2007 for the State of California (USDA Livestock Report 2007). The California Agricultural Statistics Service estimates the economic value of cattle in the livestock market to have been $2.49 billion (2007 dollars) in 2002 (the most recent census year), ranking the state eighth in the United States in livestock revenue (USDA Livestock Report 2007).

Table 4 shows the potential impacts of climate change on the livestock market. A decrease in forage production as projected with different climate models and at different future time periods directly affects estimated values of livestock or the costs of substituting missing forage with low quality hay. Excluding a slight rise in the neutral climate future scenario for 2005–2034 (with an estimated value of $15 million in livestock and $50 million in hay), most projections predict a decrease in forage production to varying degrees for all three time periods. For 2070–2099 under the high (A2) emissions scenario, the decreases from neutral climate future translate to projections of statewide economic losses ranging from (in 2007 $) $50 million to $92 million for livestock, and $170 million to $312 million for hay. Under the low (B1) emissions scenario, we project lower estimates of loss, with a range of $22 million to $70 million for livestock and $74 to $235 million for hay in the same time period. The choice of valuing forage using livestock profits or hay prices clearly makes a large difference (a factor of five) in the rough estimations provided here. This illustrates the need for a more robust and county-specific calculation of "profit-per-cow," as well as a more thorough investigation of the true cost of a substitute for lost forage production. The latter examination would most likely reveal a more accurate price than the approximation provided by equating forage to an average cost of low quality hay in California.

Conclusion: Forage Production

All models and scenarios indicate that the economic value (measured as lost profits or increased costs of feeding cattle) will be substantially lower under projected scenarios of climate change. In the near term, annual changes in profits are predicted to range from a slight increase in profits ($15 million) to losses of up to -$36 million. By 2070, the average annual profits of cattle ranching could be between $22 million and $92 million lower due to climate change. To put these figures in context, we consider what steps ranchers may take to offset losses of natural forage. We estimate that the least-cost option of replacing natural forage with hay would require that cattle ranchers spend roughly ten times this amount, for all periods and scenarios, on forage substitutes like hay. As a result of the decline in forage production, the total expected value of livestock in California would decline.

Forage production declines dramatically by the end of the century (2070–2099) in all model-emissions scenario combinations. This trend is largely promoted by increased water use efficiency under elevated atmospheric CO_2 concentration which allows woody species to establish and expand into grasslands and open woodlands. If one were to include human ignition sources into the model and browsing of woody seedlings by local herbivores, it is likely that the model results would be dramatically altered. Increased fire frequency in the desert shrub and shrub systems promotes conversion to grasslands by killing young woody seedlings and affecting recruitment.

2.3.2. Ecosystem Services With a Discussion of the Economic Value at Stake: Two Case Studies Regarding the Effects on Water

Water Quantity

Water supply is a provisioning service describing water used for extractive and *in situ* purposes. *Extractive water* use includes municipal, agricultural, commercial, industrial, and thermoelectric power uses. *In situ* use includes hydropower generation, water recreation and tourism, transportation, and freshwater fish production. Water supply can also support cultural services including spiritual uses, and aesthetic appreciation. Trade-offs are inherent in the supply of water services which are directly affected by ecosystems and climate as water moves through a landscape. This report focuses on water supply for a cultural service such as recreation (skiing) and water supply for an *in situ* service such as instream flows for freshwater fish production.

Water Quantity Provision Modeling

Streamflow

We used the projected streamflow output from the Variable Infiltration Capacity (VIC) modeling completed by Dr. Edwin Maurer for the California Energy Commission's scenarios 2008 report to estimate the projected changes in water ecosystem service production and valuation due to projected climate change. Variable Infiltration Capacity is a macroscale hydrologic model developed by Xu Liang at the University of Washington. The model takes into account energy and moisture fluxes for each modeled grid cell, including soil and vegetation cover processes (Liang et al. 1994). The VIC modeling considers only natural flows, without considering water distribution infrastructure. Representation of the current and future diversions and allocations of water throughout the state is beyond the scope of this assessment and has been addressed by other project teams. Eighteen sites were included in the VIC runs (Table 6).

Table 6. Stream gauging stations for which streamflow data were available

Gauging Station
Smith River at Jed Smith SP
Sacramento River at Delta
Trinity River at Trinity Reservoir
Sacramento River at Shasta Dam
Sacramento River at Bend Bridge
Feather River at Oroville
Yuba River at Smartville
North Fork American River at North Fork Dam
American River at Folsom Dam
Cosumnes River at McConnell
Mokelumne River at Pardee
Calaveras River at New Hogan
Stanislaus River at New Melones Dam
Merced River at Pohono Bridge
Tuolumne River at New Don Pedro
Merced River at Lake McClure
San Joaquin River at Millerton Lake
Kings River at Pine Flat Dam

Monthly modeled and projected streamflow data from 1950–2099 were compiled to assess broad trends in the timing and amount of streamflow across the model/scenario combinations to qualitatively assess changes in the associated ecosystem service value.

Climate Change and Snowpack

Many of the ecosystem services and their values that humans readily recognize are the recreational services provided by naturally functioning ecosystems. To analyze the economic implications on snow-related recreation of future changes in snowfall, we assessed the changes in maximum monthly snowpack (snow water equivalent [SWE] units in millimeters [mm] of water) for the different time periods for existing ski resorts. The snowpack data were generated by the MC1 model and were run for each of the six model/scenario combinations used in this study. We present only the results for the warmer, wetter PCM1 and the hotter, drier GFDL models to bracket the range in projected changes in climate. We calculated the average monthly maximum snowpack for the three future time periods, and we compared the changes in the snowpack to the neutral climate future runs for that time period.

Projections of Future Water Quantity Provision

Instream Flow Projections

All rivers show an increase in average flow from January to April by the end of the century (2070–2099) compared to the historical period with warmer, wetter climate projections by the PCM1 model under both the low (B1) and high (A2) scenarios. There is a spike in flow under the high emissions scenario in February (60% above historic levels) and in December under the B1 scenario (almost 40%, Figure 17). The hotter, drier GFDL projections cause an increase of 20% over historic average flows in December under the A2 scenario, resulting from a projected increase in the proportion of precipitation falling as rain (as compared to snow) in the mountains. From April to October, all model-emissions scenario combinations show a decrease in average flow with the greatest drop in June and July.

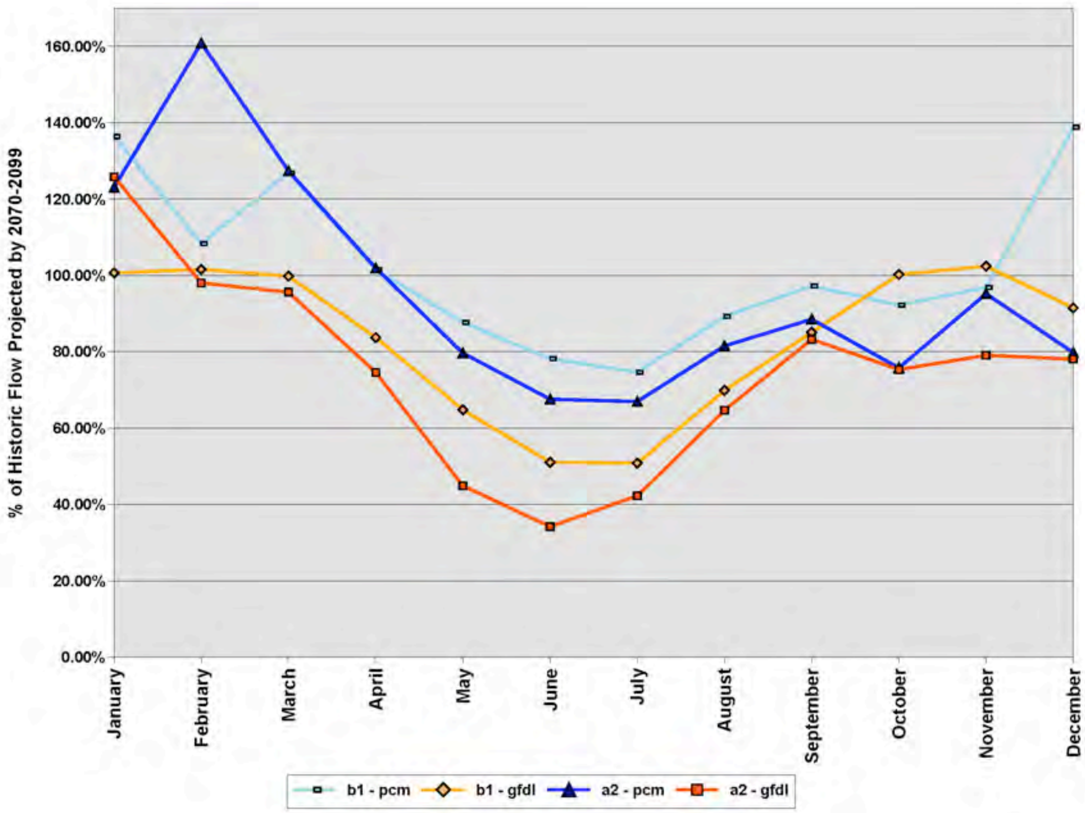


Figure 17. Projected change in monthly average flow by the end of the century (2070–2099), as compared to the historical period (1961–1990), expressed as a percentage of historic flows for each model and scenario. The monthly average flow (cubic feet per second, cfs) for the end of the century (2070–2099) was divided by the same month for the historical period (1961–1990). All models predict lower average flows from May through October.

This overall pattern of change is reflected in changes in single river flows with more consistent decreases in spring flow with the hotter, drier climate projected by the GFDL model under the A2 emissions scenario compared to the warmer, wetter climate projected by the PCM1 model, under the A2 emissions scenario (Figure 18). The PCM1 B1 model-emissions scenario combination cause the smallest change from historic conditions with no river experiencing greater than a 10% decrease in flow on average during this 30-year period, and very few rivers experiencing increases (Figure 18). The greatest increases in flow from historical conditions occur from December to March with the PCM1 model projections under the B1 scenario. The full set of average spring flows by time period and river with changes from the end of century to historical conditions are shown in Appendix C.

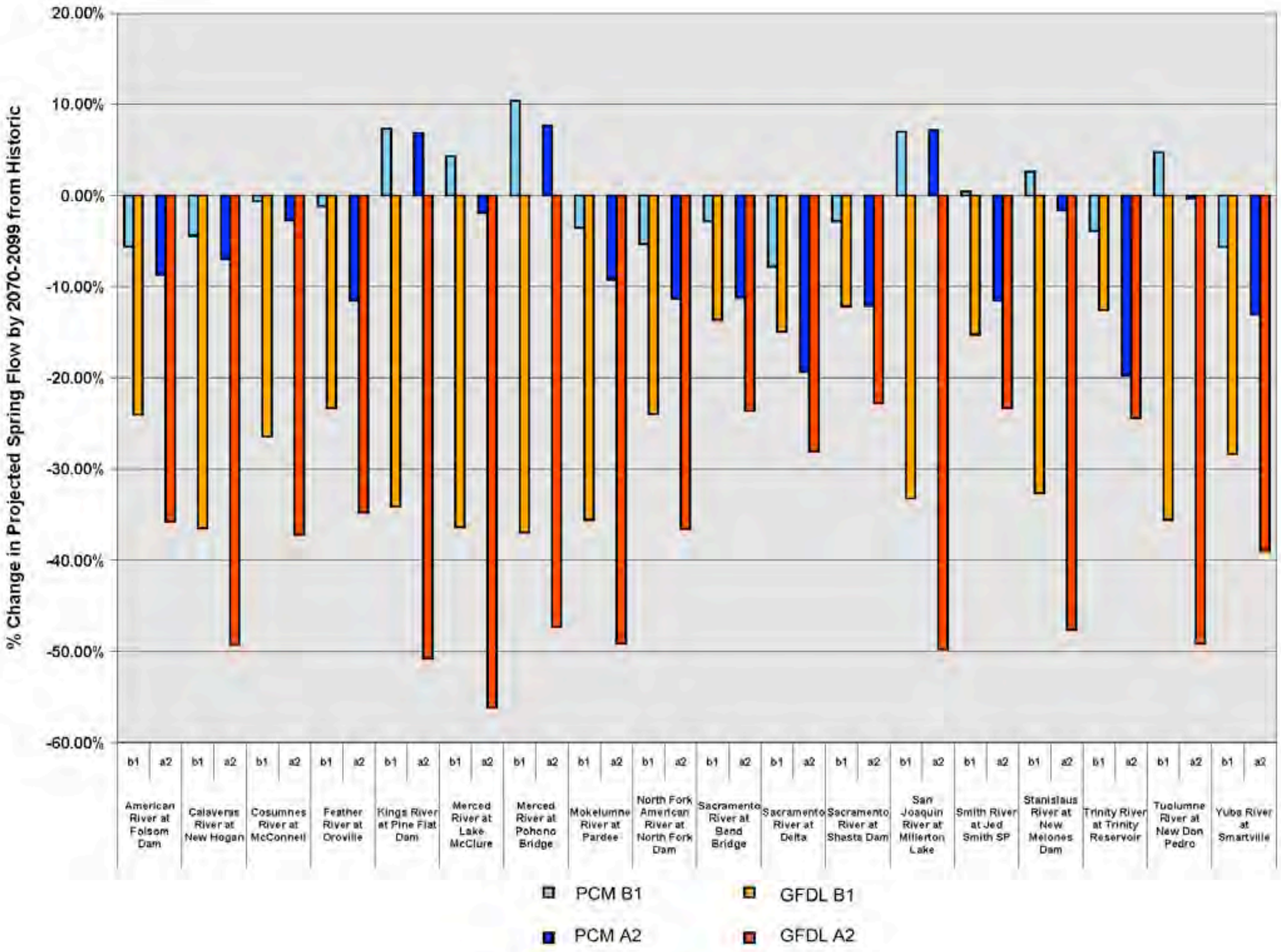


Figure 18. Projected changes in average simulated flow for all spring months (March–June) flow at the end of the century (2070–2099), compared to historical conditions, by gauging station, and across AOGCM-scenario combinations

Spatial shifts in instream flow are also important to quantify to document their impacts on ecosystem services (Figures 15 and 16). For the PCM1 B1 model-scenario combination, the changes in flow are positive for the southernmost rivers, while the average flow decreases for the northern rivers (Figure 20). The difference between the impacts of PCM1 and GFDL climate projections is also much greater in the southern rivers than the northern ones. The Chinook Salmon critical habitat for the Central Valley Spring-Run is shown for reference (Figures 19 and 20). For streamflow, the A2 scenario causes a similar pattern of change to the B1 scenario, with small increases in average spring flow in southern rivers (Figure 20). The pattern of change with the PCM1 model projections is almost linear from north to south, while GFDL model projections cause large decreases in spring flow.

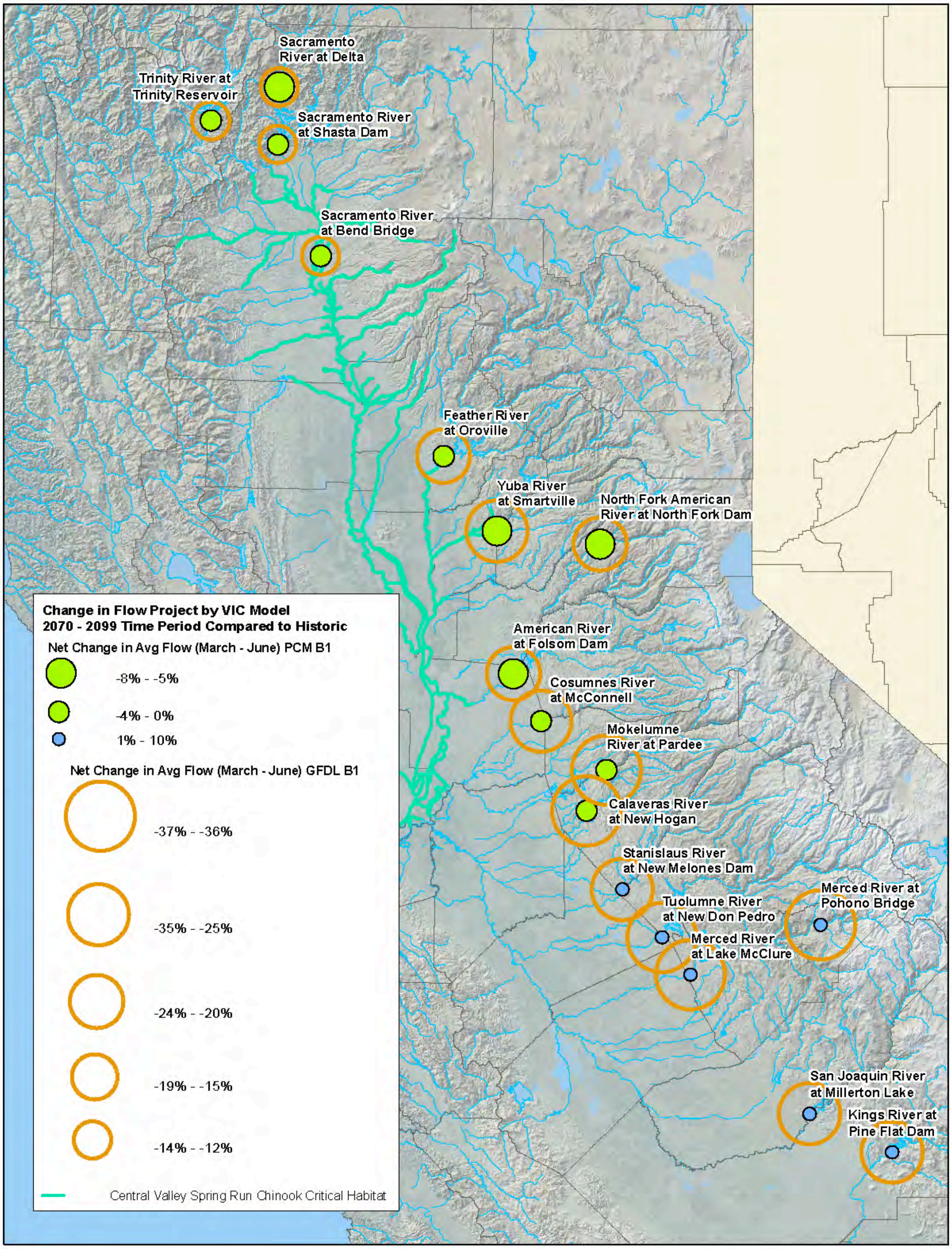


Figure 19. Net change in average flow from March through June as projected by the end of the century (2070–2099), compared to the historical period under the low (B1) emissions scenario. The circle outlines the change with the GFDL model, and the filled circles show the change with the PCM1 model.

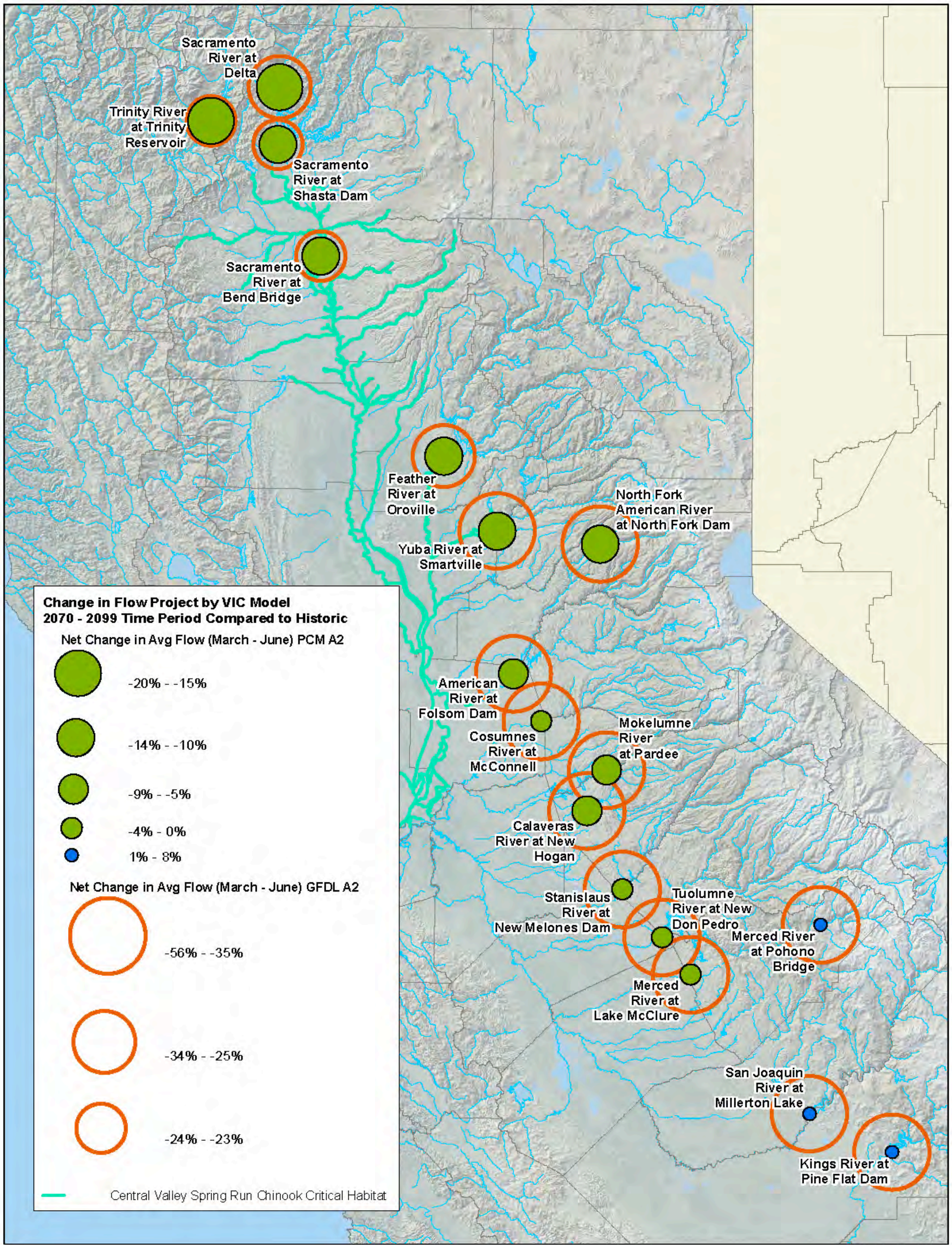


Figure 20. Map of net change in average flow from March through June as projected by the end of the century (2070–2099) compared to the historical period under the high A2 emissions scenario. The circle outlines the change with the GFDL model and the filled circles show the change with PCM1 model.

Snowpack Projections at California Ski Areas

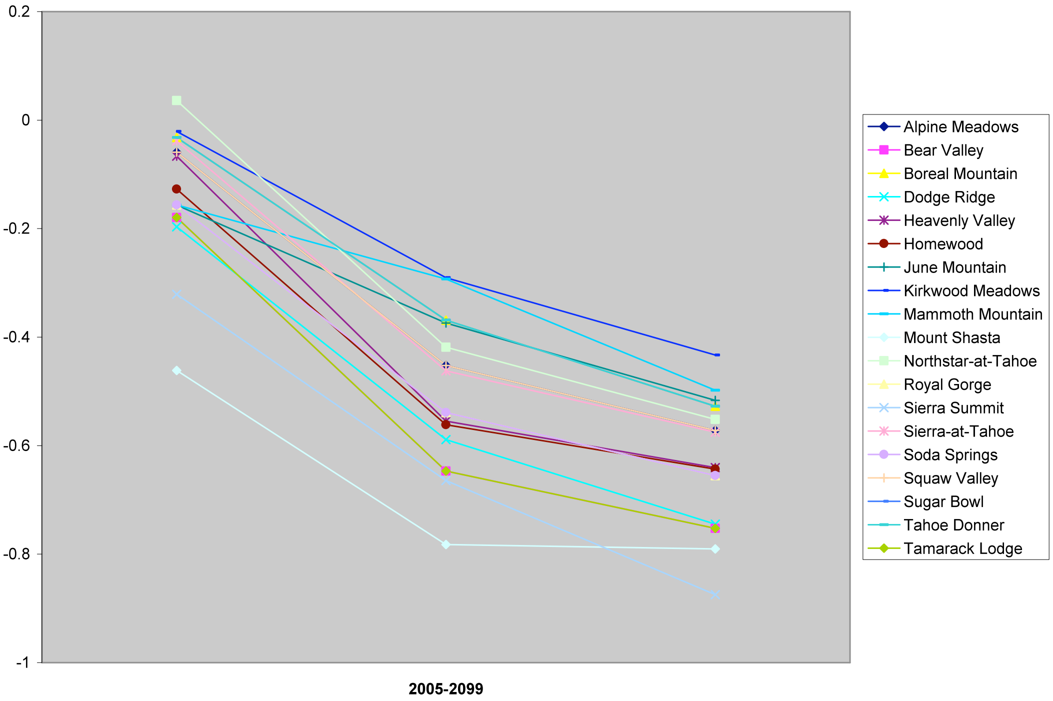
Climate change will likely result in significant changes to the distribution, quantity, and duration of snowpack available for use by the California snow sports and ski industry. Resorts located at lower elevations stand to experience a significant drop in snow-related recreation viability (Nolin and Daly 2006). Elevation and temperature are the critical variables for climate impacts on snow. In the Pacific Northwest, snowlines could shift by as much as 1100 feet towards higher elevations by 2050 with a 2.2°C (4°F) increase in temperature (National Assessment Synthesis Team 2001). Resorts located at lower elevations stand to experience a significant drop in snow-related recreation viability (Nolin and Daly 2006). A study from Oregon State University projects a large increase in the proportion of snow falling as rain throughout many of California's resort areas (Stauth 2006). The IPCC projects ski visit season losses in the Sierra Nevada region of California in 2050 to range from three to six weeks, excluding the effects of interventions like snow making (Field 2007).

Based on latitude and longitude coordinates, as well as elevation data for most of the 29 ski resorts currently operating in California, our model simulated impacts at each ski resort location for the two climate change scenarios examined. A strong downward trend in snowfall through time is projected for all ski areas under all scenarios, as shown in Figure 21 below. The data on snowfall are presented as millimeters of snow water equivalent, which reflects the depth of water that would result from the melted snow. This is a more accurate measurement than snow pillows, because depth is variable and inconsistent as settling occurs (Jeff Dozier, personal communication, August 2008).

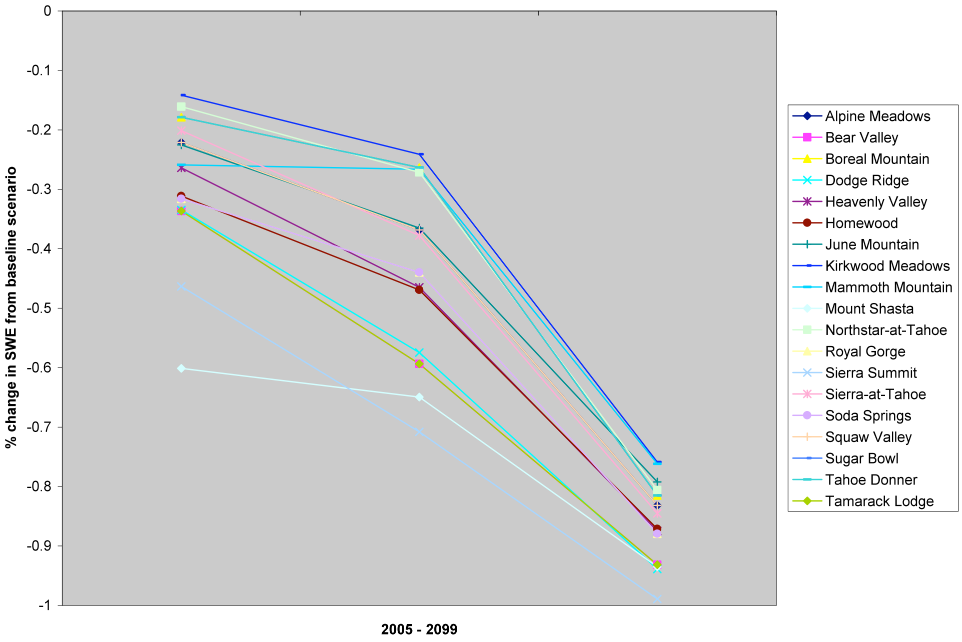
Hayhoe et al. (2004) also produced models that projected steep declines in snowpack for the state. Their study shows a dramatic decline in SWE by 2099, with many resorts receiving 70%–95% less snow than a neutral climate future scenario without climate change. All models and scenarios show a small percentage of SWE remaining at lower elevations.

Valuing the Impacts of Climate Change on Water Use

The economic values associated with the provision of surface water differ depending on the ultimate use of water. The values arise from the direct use of water by residences, municipalities and industry, irrigation for farming, and hydropower. Indirectly, surface water is an intermediate input to commercial fisheries, recreational fishing, recreational boating, and snow-related recreation. These intermediate services, in turn, affect the production of end uses or final services. For instance, change in instream flow impacts commercial fisheries, recreational fishing, recreational boating, municipal and industrial use, irrigation, hydropower and flood mitigation. Change in snowpack can affect related recreation (skiing/snowmobiling), flood mitigation, municipal and industrial use, and hydropower. Excessive surface water can also provide an economic disservice or economic cost by creating flooding and causing coastal and freshwater pollution that can affect beach and other recreation.



a. Hotter, drier GFDL Model for Low (B1) Emissions Scenario (% change in snow water equivalent [mm H20] from neutral climate future)



b. Hotter, drier GFDL Model for high (A2) Scenario (% change in snow water equivalent [mm H20] from neutral climate future)

Figure 21. Projected decline in snowpack at Ski Resorts in California during the 21st century, under both low emissions scenario (a) and high

emissions scenario (b) for
the hotter, drier climate (GFDL model)

In addition to this paper, the economic value and importance of water use and potential climate-driven changes in these values is being addressed by at least three other Scenarios 2008 projects: climate change impacts on hydropower (Madani and Lund 2008), municipal/industrial (Hanemann and Vicuna 2008) and agriculture use of surface water (Joyce et al. 2008). We focus our research on examining the impacts of climate change on ecosystem service production—an economic aspect of value change that is not considered by the other studies. With this in mind, we identify two important ecosystem services that may change due to the affect of climate change on precipitation patterns: snow-related recreation and commercial and recreational fishing.

Economic Impacts on the Snow Recreation Industry

The economics of the ski industry are likely to be heavily affected by a changing climate. Currently, Scott and McBoyle (2007) report that the entire U.S. ski industry generates an estimated $9 billion of direct revenue. The California Ski Industry Association estimates that skiers in California enjoyed 7.2 million visitor days (80% of which are local visits from within California) during the 2007/2008 ski season, and in the process spent, and thus generated an economic impact of, more than $500 million, including expenditures on lift ticket, rentals, parking, and other related activities. Visitation records for California ski areas are collected by the California Ski Industry Association from each resort's general manager under a confidentiality agreement. The breakdown, nationwide, of these gross expenditures by category is shown in Table 7 below:

Table 7. National Ski area revenue source, 2007

Revenue sources (%)	1974–1975	2001–2002
Lift tickets	79.4	47.4
Food and beverages	2.8	14.1
Lessons	2.8	9.8
Accommodations/lodging	1.8	9.4
Other	2.1	7.2
Retail	1.5	5.5
Rentals	4.5	5.3
Property operations	5.1	1.2

Data source: National Ski Area Association (NSAA) annual state of the industry reports
Table source: Scott and McBoyle 2007

The Economic Value of Skiing in California

Skiing opportunities in California also contribute to the economic well-being or value of Californians. These additional values, called *non-market values* or *consumer surplus,* reflect the willingness of skiers to pay to ski, beyond what they actually pay. In California, this non-market value reflects the convenience and quality of skiing at nearby ski areas within the state. Each year the state attracts over a million out-of-state and international visitors. It is likely that the convenience and quality of skiing in California generate substantial economic value from this large number of local visitors and thus ski areas create a consumer surplus for visitors enjoying the slopes and resorts in California. Like other uses of public recreational areas, a full understanding of the economic value of skiing requires that we estimate its market and non-market value together (Kaval 2006, p.2).

Existing literature provides a variety of estimates for the non-market value of skiing in California and other western states (Kaval and Loomis 2003; Rosenberger and Loomis 2000; Vaske et al. 1980; Bergstrom et al. 1991; Coupal et al. 1997; Walsh et al. 1983; Walsh et al. 1984). To approximate the non-market value of snow in California under different climate scenarios, we use estimates of consumer surplus for downhill and cross-country skiing derived by a meta-analysis of non-market consumer surplus values for outdoor recreation in the United States. This study included a total of 1,229 observations over 30 years and a mean sample size of 1,460 (Kaval 2006). In the study, Kaval and Loomis estimate the non-market values of downhill skiing for the Pacific Coast Region (California, Washington, and Oregon) to be $24.14 per person per day in 2007 US$. For 2007/2008, this equates to around $174 million (in 2007 US$) for downhill skiing in California. It should be noted that Kaval's consumer surplus value estimates for cross-country skiing in the Pacific Northwest and snowmobiling in the inter-mountain region (western Wyoming, Utah, Idaho, Nevada and portions of Colorado and California) are $46.95 and $51.88 respectively, per person per day, in 2007 US$, showing a significantly higher level of consumer surplus for each of these other snow-related activities. Because we use the lower value of $24.14 for all skiing, our findings should be considered conservative.

Climate Impacts on Snowpack at California Ski Areas

Reduced snowpack and higher temperatures have been shown to decrease ski resort visitation demand generally (Englin and Moeltner 2004). The CSIA estimates approximately 7.2 million visitor days to ski resorts in California and a total spending at resorts of approximately $500 million in 2007/2008. Should a 70%–95% decrease in SWE occur, as projected by the GFDL model under the A2 climate scenario, visitation and thus expenditures are likely to decrease significantly due to a severely reduced number of available ski days (reflected by a shortened ski season and fewer resorts located at higher elevations), but the exact magnitude of this decline is difficult to predict at this time because shrinking local availability of ski days may serve to increase the local price of lift tickets.

Snowmaking can play an important role in mitigating decreases in snowfall and should be adequately accounted for in a thorough quantitative study of the ski economy's responses to climate change (Scott et al. 2002, 2003). Many of the lower elevation, southern California resorts (Bear Mountain, Snow Summit, and Mountain High) already rely almost entirely on snowmaking (Jeff Dozier, personal communication, August 2008). This is a costly activity, with prices close to $1000/acre-foot of snow, plus the cost of the water itself (Gelt 2006). However, snowmaking requires freezing temperatures, and since all of the future scenarios of climate change project increases in temperature year round, the ability to make snow will be limited for some resorts.

The Change in Economic Value Due to Climate Change and Changes in Snowpack on the Ski and Snow Recreation in California

As mentioned earlier, skiing in California generates economic value to skiers that may not be captured by ski resorts. We estimate this value to be approximately $174 million annually. Decreased snowfall combined with increased average temperatures are likely to lead to a decline in the demand for skiing and thus a reduced economic value to skiers, even those who continue to ski in California. If higher elevation resorts retain their desirable characteristics while lower elevation locations experience reductions in snowfall (and quality), demand will likely shift to the higher elevation locations or to out-of-state ski areas. Substitution to higher elevation resorts, however, is unlikely to completely offset losses at lower elevation ski resorts. First, if higher elevation resorts are farther from population centers, the average cost of making a ski trip will increase for California skiers and these increased costs will result in fewer trips, all other factors staying constant. Second, the consumer surplus enjoyed by skiers will undoubtedly fall for most California skiers if we assume that the fewer options for skiing necessarily means fewer choices for skiers. The concept is a common one in economics and suggests that if all sites currently receive visits, then it must be the case that each site is the optimal site for at least those visitors that choose those sites. Finally, if more visits are made to the remaining sites, congestion is likely to become a problem, further reducing the demand for, and enjoyment from, skiing at California ski resorts (Walsh et al. 1983). Walsh et al. (1983) examined congestion's role in decreased willingness to pay for lift tickets at resorts in Colorado by considering the impacts of lift-line waiting time and the number of skiers per acre. They measured the benefit newly available areas of skiing provide by relieving congestion in currently over-used areas, and they examined individual willingness to pay (i.e., how much a skier would be willing to pay) for reduced congestion in the existing sites. A decreased season length, due to less snowfall, has also been shown to correlate with higher participation on the days that skiing is still possible (Scott and McBoyle 2007). This is mostly like due to more people squeezing their skiing into fewer available days.

To conclude, snowpack in California supports substantial market and non-market values related to skiing. We estimate the market impact of direct expenditures from ski resort to be on the order of $500 million annually and the non-market value of skiing to Californians to be approximately $174 million. Climate change puts both market impacts and non-market values at risk, but to date we are unable to predict exactly how these values are likely to change due to climate change and change in snowpack. Given the large magnitude of these values and the demonstrated sensitivity of skiing to snowpack, we recommend further research on the effects of snowpack on California skiing, including a better understanding of how California skiers will use substitute sites in other states or substitute activities within California.

Economic Impacts of Climate Change on Salmon Fishery

Climate change is likely to have a serious impact on salmon production and the recreational and commercial fisheries that depend upon them. The primary effects of climate change on salmon include stream temperature and precipitation-related changes to the quantity and timing of stream flow, especially the timing of spring runoff and average flow (Flemming et al. 2002; Pendleton et al. 1998; Anderson et al. 1993). Anadromous species of salmon—those that live in the ocean but reproduce in rivers and streams—migrate hundreds of miles as part of their natural reproductive cycle. Because of the wide ranging nature of salmon in the ocean, salmon caught in California coastal waters may reproduce in streams and rivers in California or elsewhere along the Pacific Coast of North America. Similarly, it is possible that salmon that reproduce in California streams and rivers may be the target of commercial fishers and sports anglers in other states.

Our current understanding of the quantitative links between climate change, salmon abundance and distribution, and economic impact and value is incompletely developed for California.

Nevertheless, because salmon is an iconic species and one likely to be highly sensitive to climate change, we briefly describe here the potential economic impacts that climate change could have on the salmon fisheries in California. We consider how changes in stream flow might affect salmon populations and provide a short discussion about how we might value such potential changes in salmon populations.

As shown in the water quantity provision models above, all rivers show a future increase in average flow between January and April, compared to historic conditions. These projected changes in river hydrology result from earlier snowmelt and increases in the elevation at which freezing occurs. Such changes will result in decreased summer runoff and increased winter runoff. The egg incubation period generally occurs between mid-October and mid-February. If climate change results in increased peak flows (winter flows) as the models projects, gravel shifts caused by flooding may become more frequent and larger, making eggs more vulnerable to destruction (Flemming et al. 2002; Battin et al. 2007). Increased flows may also occur when juveniles are emerging, making them more susceptible to displacement.

During the spawning period, climate change is likely to decrease average flow. In this case, adult salmon will encounter lower river flows during their pre-breeding migration which may impede their passage upstream because some river obstacles can only be passed during high flow conditions. Delays in reproduction and mortality may then occur, particularly in cases where the spring flush that results from snowmelt is substantially reduced. Low flows are also expected to select against large adult body size, which could result in reduced size of harvestable salmon (and thus their associated value) in many rivers.

Climate-driven changes in stream flow have been predicted to change the abundance of spring Chinook salmon from the Yakima sub-basin that could be available to fishers (Chatters et al. 1991 and Anderson et al. 1993). While a specific model for California stream and river systems does not exist, it is likely that the effects would be similar.

Anderson et al. (1993) attempts to estimate a more comprehensive economic value of the potential impact of climate change on Chinook salmon by calculating the sum of a variety of economic impacts, including market impacts and non-market impacts associated with use and non-use values for salmon. They include recreational value, existence value, capital value and other values of an adult spring Chinook salmon in their estimate. Because of limited data regarding the value of California salmon, we focus on two important components of this "total value" of salmon—recreational value and commercial value. *The recreational value* represents the probability of a Chinook salmon being caught by a recreational angler times the current estimated average recreational value of fish. *Commercial value* is the probability of a Chinook salmon's being caught commercially times the current estimated average commercial value.

We look specifically at the ways in which climate change may affect the economic impact (measured as gross revenues from commercial fishing and expenditures by recreational fishers) and non-market value of Chinook salmon that live and reproduce in California's Central Valley which includes the ocean fishery for Chinook salmon south of Point Arena. An exhaustive review of the growing literature on salmon and salmon values is beyond the scope of this report. We do, however, provide a brief review of selected findings that are particularly relevant to California

Commercial Value

The Pacific Fishery Management Council provides estimates of the Chinook stocks and includes the sum of ocean harvests of Chinook from the Klamath River area, as well as the Central Valley, south of Point Arena plus the Central Valley adult Chinook spawning escapement (PFMC 2008). According to PFMC estimates, the average size (1998–2008) of the Chinook salmon run is 796,810 fish (PFMC 2008), with an annual harvest rate of 31%. In the Klamath River, the average size of the Chinook salmon run is 515,660 and the average harvest rate is far lower at 9.7%.

To determine the gross economic revenues generated by the commercial fishing of Chinook salmon for the State of California, we use data from the Pacific Coast Fisheries Information Network (Pacfin) to calculate the 10-year (1998–2008) average ex-vessel revenue, adjusted for inflation. The ex-vessel revenue represents the amount of money paid to the fisher at the time fish are off-loaded from the fishing vessel. Over the last ten years, commercial fishers earned an average of $13 million (in 2007 inflation adjusted dollars) annually in (ex-vessel) revenues associated with salmon fishing in California, nearly all of which was Chinook salmon. The PFMC estimates that more than 245,000 of the salmon caught by California vessels were dependent upon Central Coast streams and resources.

The gross revenues of the commercial salmon fishery do not reflect the "economic value" of the future fishery. First, the economic value of the fishery is more closely related to the net revenue generated by the fishery—revenues minus costs. Hackett and Hansen (2008) report that following the dramatic decline in the salmon fishery from 2005 to 2006, the net revenues of salmon only fishing in the state were strongly negative (-$4.8 million) with more than 69% of the fleet experiencing negative returns. Even at its peak of $25.6 million in 2004, these gross revenues only indicate the maximum possible returns—net revenues are always a fraction of these gross receipts. Second, while gross revenues do not capture economic value, they do represent economic throughput which helps to support jobs, wages, and taxes. A 2001 study by Niemi et al. found that in the Pacific Northwest, 1.5 full-time jobs were created for every thousand salmon caught commercially.

Recreational Value

Salmon are targeted by sport anglers in coastal waters of California and in the streams and rivers where salmon reproduce. We know that ocean sport fishers landed an average (1998–2008) of 96,900 Chinook salmon per year in the Central Valley region. Data collected by California Department of Fish and Wildlife in 1998, 1999, 2000, 2001, 2002, and 2007 show that river anglers in the Central Valley region also landed an average of 71,200 Chinook salmon and released approximately 28,900 annually, with a total annual catch of approximately 100,200 Chinook. Over the period for which we have data, more than 197,000 Chinook salmon were caught on average by ocean and freshwater anglers in the Central Valley.

Like other ecosystem values discussed in this report, salmon have both market value (economic impact) and non-market value. More so than other ecosystem services considered here, salmon also have important and well-established cultural values.

A variety of studies have attempted to value salmon using non-market valuation techniques. The results provide a wide range of values. Johnston et al. (2006) conducted a meta-analysis of recreational fishing values and found that the marginal value of Chinook salmon ranged from $3.99 to $327.59, and depended upon attributes of the angler, the abundance of salmon, and the attributes of the natural environment. Studies by Niemi et al. (1999 and 2001) estimated that the value of an additional salmon caught in the Klamath River would be worth $136/fish (in 2007 dollars) beyond what anglers already pay for access, bait, and tackle. These marginal values reflect the value of one more salmon caught or not caught, but do not help us estimate an overall non-market value of the existing recreational fishery for salmon in California. Another measure of the value of recreational salmon fishing is the average non-market value of a day spent salmon fishing. Pendleton and Rooke (2008) review the literature and find that the non-market value of a recreational sportfishing trip in California $15 to $97/day. The non-market value of trips dedicated solely to salmon and/or halibut are $99 to $146/day for recreational angling in Alaska (Hamel 2000). Without an estimate of the average recreational value of a salmon or the total number of trips dedicated to salmon fishing in California, it is impossible to estimate the total potential non-market recreational value of the fishery.

Like commercial fishing, recreational fishing for salmon also generates substantial market impacts. Niemi et al. 2001 estimate that every salmon caught in the Pacific Northwest may result in $99 (in 2007 dollars) of expenditures per fish, on average and as many as four jobs for every thousand salmon caught. Meyer Resources (1997) estimate recreational expenditures of $110/fish (adjusted to year 2007.) The National Marine Fisheries Services (2006) estimated that expenditures associated with salmon fishing south of Point Arena averaged almost $15 million in year 2007 dollars. Based on these preliminary figures, we estimate that recreational salmon fishing in California may generate on the order of $20 million in gross revenues for local businesses and as many as 200 full-time jobs.

It is important to note that recent declines in salmon stocks, caused by water shortages and habitat change and destruction have depressed the economic contribution of salmon to California's recreational economy. Climate change will likely make efforts to restore salmon fisheries considerably more difficult, but it is difficult to know how climate change and other causes of decline in salmon population will interact.

Conclusion: Water Provision

One of the most profound shifts in ecosystem service provisioning in the future will be the changes in water availability supporting humans and nature. Under all models and emissions scenarios, California rivers show an increase in average flows in the winter as a result of more precipitation falling as rain instead of snow. Consequently, all model-scenario combinations show a significant decrease in average flow in the dry months, with the greatest drop in June and July.

Snowpack for Skiing

Snowpack in California supports substantial market and non-market values related to skiing. The changes in the magnitude, form and timing of precipitation are likely to result in significant impacts to the snow recreation industry. The decrease in overall number of ski and snow-boarding resort visits (from fewer snow recreation areas) provide a preliminary estimate of the potential economic impact that may result due to changes in snowfall. With approximately 7.2 million visitor days to ski resorts in California and a total spending of approximately $500 million in 2007/2008, a 70%–95% decrease in snow water equivalent will decrease the total value of the industry. While the non-market impact of direct expenditures from ski resorts is on the order of $500 million annually, the non-market value of skiing to Californians is approximately $174 million. Climate change puts both market impacts and non-market values at risk, but to date we are unable to predict exactly how these values are likely to change due to climate change and change in snowpack. Given the large magnitude of these values and the demonstrated sensitivity of skiing to snowpack, we recommend further research on the effects of snowpack on California skiing, including a better understanding of how California skiers will use substitute sites in other states or substitute activities within California.

Instream Flows for Salmon

The salmon fishery has been a modest, but locally important component of the state's commercial and recreational fisheries. While little data exist to demonstrate the exact economic contribution of the salmon fishery, we estimate that the salmon fishery has supported as much as $33 million in economic throughput ($13 million in gross revenues from commercial fishing and $20 million in gross expenditures by recreational anglers) on average each year. Clearly, climate change threatens both the commercial and non-market values associated with recreational salmon fishing.

In addition to the direct use value, salmon are important for a variety of other reasons, including their role as important components of riverine ecosystems, icons of nature, and as spiritual and cultural figures for native Californians. Numerous studies have attempted to place a value on these non-use values for salmon inhabiting other parts of the country (see for instance Layton et al. 1999 or Bell et al. 2003).

Salmon and the values associated with them are indicative of many other species that depend on stream flows. Many other fish, including trout and other freshwater game fish, bears, birds, and a variety of other animals and plants will likely be affected directly by changes in stream flows. Downstream, numerous species that depend on salmon as prey also will likely be affected by climate change. In this section, we briefly outlined how these important species contribute to local revenues, jobs, and economic well-being. Further research is needed to better understand the economic importance of these species and the impacts that climate change may have on these values.

2.3.3. Climate Change and Its Effects on Other Ecosystem Services: The Case of Biodiversity Change

In the above, we provide selected examples of how climate change may affect ecosystem services that support important economic activities and values in California. The effects of climate change on ecosystems and services, however, is likely to be widespread, affecting the functioning, range, and composition of most terrestrial, aquatic, and marine ecosystems. In some cases (e.g., land and forest cover) there are direct and obvious impacts of climate change on economically important ecosystem attributes. In other cases, including the impacts of climate change on marine ecosystems, the effects of climate change will be more difficult to see. Much of what happens in ecosystems is largely out of view.

One important aspect of ecosystems that often is outside of public view, and thus is difficult to value, is the contribution of biodiversity to the economic well-being of Californians and the functioning of the California economy. Biodiversity represents the number and proportion of species in the ecosystem. Biodiversity also reflects the increasing rarity of many species. We already live in a period of unprecedented loss of many important species, and climate change is likely to affect the ability of species to adapt to other changes in ecosystem and environmental condition. Loss of these species, especially species that people know and enjoy directly, will have an impact on the economic well-being of local Californians and tourists who come to

California, in part or specifically, to see such species as otters, redwoods, sequoias, condors, and many more plants and animals. Loss of these species also will affect the resiliency of ecosystems to withstand climate-related shocks, including those caused by fire, drought, severe winters, and habitat loss. A loss of resiliency, in turn, can lead to the loss of other important species and ecosystem services, including watershed protection, agricultural windbreaks, flood control, soil creation and protection, oxygen production, the natural mitigation of waterborne and airborne pollutants, and even climate control. A loss of resiliency also can make ecosystems and habitats more vulnerable to invasive species, including species that are direct competitors with farming, fishing, and hunting; species that are pests; and species that threaten public infrastructure (e.g., zebra mussels). In this section, we look at the effects that climate change may have on terrestrial biodiversity, especially the distribution of rare species. Our goal in this section is to demonstrate the potential magnitude that climate change may have on the basic functioning of ecosystems, especially the genetic and species integrity of ecosystems. The analysis serves as an example of how broad our thinking on the matter of climate change and ecosystem services should be and how little we know of the total economic impacts of climate change on these ecosystems. We do not discuss the impacts of climate change on aquatic and marine ecosystems and their biodiversity and resilience, but note these impacts are likely to be as substantial and difficult to assess.

Biodiversity Modeling

To assess projected impacts of climate change scenarios on biodiversity in California, we construct ensemble species distribution models (SDMs) (Araujo and New 2007) for terrestrial species that forecast temporal changes in bioclimatic suitability. Summaries of modeled species responses help compare the magnitude and direction of geographic shifts expressed by changed in elevation, latitude, longitude, and percent area. We relate projected shifts to factors expected to drive responses, including emissions scenarios, global climate models, and broad taxonomic groups (Thomas et al. 2004). Species distribution models derive ecological relationships between field observations and spatial predictors using alternative statistical methods (e.g., Bioclim, Domain, and Maxent) (Austin 2002). The resulting ecological relationships can be easily projected into alternative climate scenarios and time periods.

Most species distribution modeling methods make two fundamental assumptions: (1) that species distributions are in a state of equilibrium with respect to the current environment, and (2) that all factors limiting the distribution of the organism are considered in the model. These simplifying model assumptions remain untested here, but the urgency of climate change dictates some action in lieu of complete knowledge about the system (Austin 2006). The SDMs in this study are designed to reconstruct species' potential distributions through time, as defined entirely by abiotic (climatic) limiting factors. We anticipate these SDMs over-predict organisms true distributions (Thuiller 2004), given we make no attempt to distinguish between the effects of past climates on current distributions (Araujo and Pearson 2005), and we do not incorporate significant limiting factors such as biotic interactions (Guisan et al. 2006) and dispersal limitation (Pearson and Dawson 2003).

Despite these standard caveats, our approach allows us to test two general questions about how climate change scenarios may affect California biodiversity. First, we ask how model projections vary with respect to emissions scenarios, AOGCMs and/or taxonomic groups. Second, we ask whether model projections support simple theoretical predictions that organisms may migrate poleward and/or uphill to track shifting climate spaces (Parmesan and Yohe 2003; Parmesan 2006).

Biodiversity Occurrence Data

This study models climate change impacts for 240 rare and imperiled terrestrial species described in the California Natural Diversity Database (CNDDB) (California Department of Fish and Game 2008), including amphibians (n=12), birds (n=29), invertebrates (n=7), mammals (n=25), reptiles (n=13), and plants (n=154). Using ArcGIS (ESRI 2006), a series of filters were applied to the available CNDDB records prior to modeling (n=58,503 total), resulting in the dataset qualified for this analysis. First, only terrestrial species were selected, including amphibians. Purely aquatic targets were excluded based upon a lack of statewide spatially explicit time-series hydrology data.

Second, records were excluded if they lacked data necessary for biodiversity analysis, including those lacking community observations, maintaining low positional accuracy (> 1 mile), and that were non-natives, and/or species with low conservation status (both global and state conservation rank > 2). Third, historical observations dating from 1860 to 1959 were excluded due to low spatio-temporal resolution in the dataset. Fourth, we reduced the remaining records to a subset of current (1960 to the present), using only those that had at least 10 spatially unique occurrences at a 12 km resolution falling within the study area (n=4404). In all, the final species selected for niche modeling include only terrestrial species of high conservation interest with > 10 spatially unique current observations. The complete list of species names, common names, taxonomic groupings, and unique observation counts are listed in Appendix A.

Climate Data Preparation

Inputs for climate data were prepared as annual mean monthly climate grids (1960–2099) for minimum temperature, maximum temperature, precipitation, soil moisture of the top layer, and net radiation. From these data, we derived 35 bioclimatic variables summarizing seasonal indices of temperature, precipitation, soil moisture and radiation using an amended form of an .aml script by R. Hijmans (www.worldclim.org/mkBCvars.aml).

Species Distribution Models

For each species, climate scenario, and temporal projection, we generate species distribution based upon alternative statistical methods of species distribution modeling—Bioclim (Nix 1986; Busby 1991), Domain (Carpenter 1993), and Maxent (Phillips et al. 2004; 2006)—in the hopes of drawing upon comparative methodological strengths and weaknesses of each (Elith et al. 2006; Hijmans and Graham 2006). Inference in these methods is driven by correlative patterns between observations in the field and environmental attributes, but there is no formal mechanistic description about the underlying processes governing distributions (Kearny and Porter 2004; Kearny 2006; Monahan and Hijmans 2008). Maxent models were generated using java freeware version 3.2.1 with the default settings for convergence threshold (10^{-5}) and maximum number of iterations (500). Maxent model output grids result in a continuous range of relative suitability scores (0–100), based upon the principle of maximum entropy. Bioclim and Domain models were generated in R (R Development Core Team 2007) using modified versions of scripts used to validate how well projections based upon rich historical datasets recover current observed distributions (Monahan and Langham 2008). The domain function implemented in R required the adehabitat (Calenge 2006) and ade4 packages (Chessel et al.

2004; Dray and Durfour 2007; Dray et al. 2007). Processing of ASCII climate grids and species point data in R required standard spatial packages, including fields (Furrer et al. 2008), foreign (DebRoy and Bivand 2008), maps (Becker et al. 2008), maptools (Lewin-Koh et al. 2008), sp (Pebesma and Bivand 2005), and spam (Furrer 2008). Bioclim models were built on the principle of multivariate rectilinear envelopes, where outputs values are integers equaling the number of predictor variables falling within 95% confidence intervals of species observations for any given grid cell (i.e., 0–35). Domain models are driven by a continuous point-point similarity metric where output values are a continuous range of relative suitability scores (0–1000).

To compare directly between SDMs (n=5760), we reclassified continuous grid values in raw model outputs as binary grids which then allowed us to convey projected suitable areas versus unsuitable areas. For each current SDM (i.e., representing one species, one climate scenario, and one niche method from 1961–1990), we calculated the minimum model value that correctly predicted 95% of our known species observations as suitable. Threshold values calculated for each current SDM were then applied to all three associated future temporal projections (i.e., 2005–2034, 2035–2064, 2070–2099) resulting in comparable projections of climatic suitability across all models.

For summary statistics, we compared current versus future models, and calculated: (a) how mean elevation, mean latitude, and mean longitude values change across time for predicted areas of suitability; and (b) how area versus percent area varies in terms of projected distribution contractions, expansions, and stability across time. Summary statistics were derived in R by calculating the mean grid cell value returned from the product of two grids: a binary SDM (where 1= "suitable" and "0" = unsuitable) independently multiplied by a grid representing three perspectives on geographic position (elevation, latitude, and longitude). The summary statistics for area were derived in R by stacking scaled forms of our current and future SDMs, to distinguish between areas predicted in only current, only future, or both current and future projections, and then multiplying those scaled surfaces by a grid cell area. Summaries from different modeling methods (Bioclim, Domain and Maxent) were qualitatively similar when considered across emissions scenarios, climate models and taxonomic groups, therefore we present model averages for all point estimates.

2.3.4. Projections of Future Biodiversity Impacts

Results from the rare and imperiled terrestrial species distribution model runs suggest broad trends that fit well with *a priori* expectations of species responses to climate change: movement poleward, coastward, and upslope and greater responses under the high emissions scenario. In comparison to low emissions scenarios (B1) by the end of the century, higher emissions (A2) projected much larger species migrations to track shifting climates (poleward, uphill, and coastal in Table 8) , as well as larger overall contractions of suitable areas (Figure 22). The future climate projected by the hotter, drier GFDL model is hotter and dryer than the one projected by PCM1 and, as a result, the magnitude of the simulated species responses is greater. Comparatively, simulated responses to warmer, wetter climate under the high emissions scenario (PCM1-A2) are similar to responses to drier, hotter climate under the low emissions (GFDL-B1) (Figure 22). In general, projections of suitable climate space for rare and imperiled terrestrial species broadly support progressive, directional shifts poleward and coastward (1s–10s of kilometers), as well as upslope (10s—100s of meters). Notably, areas with the most stable, suitable climates (potential future refugia) diminish rapidly through time and under the higher emissions scenario. In addition, the direction and magnitude of transitions from suitable to unsuitable areas (contractions) are consistent across all major taxonomic groups, despite geographic and ecological differences. When examining the individual species responses, we find less uniformity; nevertheless, a strong signal of shared biological response is present in the data. Some areas that maintain unsuitable climate today may transition to suitable climate in the future (expansion), which may offset losses, depending on the dispersal limitations and species-specific habitat requirements. Whereas predicted contractions appear uniform across taxonomic groups, expansion estimates vary considerably, with some groups balancing gains and losses (i.e., plants, invertebrates, and reptiles), and others projecting only small, irregular gains relative to steady losses (i.e., amphibians, birds, mammals, Table 9). Further analysis is required to explore how spatial responses vary by ecoregions.

Table 8. Statewide average projected change in mean latitude, longitude, and elevation rare and imperiled terrestrial species in California by time period, emissions scenario, and AOGCM

TAXA	SCEN	AOGCM	Δ LATITUDE (km)			Δ LONGITUDE (km)			Δ ELEVATION (m)			N
			T1	T2	T3	T1	T2	T3	T1	T2	T3	
PLANTS	*B1*	*PCM1*	-8	9	16	9	-8	-11	32	37	99	*154*
		GFDL	5	20	32	-4	-15	-30	78	126	166	
	A2	*PCM1*	-3	8	17	-2	-12	-13	23	46	186	
		GFDL	9	25	41	-13	-23	-43	74	151	333	
INVERTEBRATES	*B1*	*PCM1*	-21	-10	26	23	10	-8	41	37	70	*7*
		GFDL	26	22	48	-9	-4	-23	45	118	136	
	A2	*PCM1*	3	8	22	-4	-6	-2	13	43	157	
		GFDL	11	35	46	-4	-16	-12	61	136	321	
AMPHIBIANS	*B1*	*PCM1*	4	15	21	1	-8	-8	35	43	100	*12*
		GFDL	21	24	30	-7	-10	-19	95	153	170	
	A2	*PCM1*	-2	10	20	-2	-9	-1	21	43	204	
		GFDL	8	40	43	-4	-30	-31	105	128	293	
BIRDS	*B1*	*PCM1*	2	11	17	0	-9	-14	8	22	43	*29*
		GFDL	10	23	31	-8	-18	-33	37	74	89	
	A2	*PCM1*	0	13	24	-2	-14	-19	9	22	94	
		GFDL	11	9	16	-15	-18	-45	37	66	167	
MAMMALS	*B1*	*PCM1*	4	10	11	1	-8	-8	18	39	79	*25*
		GFDL	5	17	26	-2	-13	-26	75	126	134	
	A2	*PCM1*	-1	13	11	-1	-12	-6	17	37	154	
		GFDL	8	9	13	-12	-14	-34	57	132	280	
REPTILES	*B1*	*PCM1*	-2	10	30	2	-12	-32	-9	9	26	*13*
		GFDL	13	21	29	-20	-31	-48	35	71	75	
	A2	*PCM1*	9	18	17	-11	-23	-24	-8	7	103	
		GFDL	7	6	36	-25	-29	-73	28	67	182	
MIGRATION INFERENCE			POLEWARD = (+)			COASTAL = (-)			UPHILL = (+)			

Table 9. Statewide average projected change in range size for rare and imperiled terrestrial species in California by time period, emissions scenario, and AOGCM

TAXA	SCEN	AOGCM	% FUTURE REFUGIA by CURRENT SUITABILITY			% FUTURE EXPANSIONS by CURRENT SUITABILITY			% FUTURE CONTRACTIONS by CURRENT SUITABILITY			N
			T1	T2	T3	T1	T2	T3	T1	T2	T3	
PLANTS	*B1*	*PCM1*	69	71	60	23	19	26	31	29	40	*154*
		GFDL	64	58	48	35	30	33	36	42	52	
	A2	*PCM1*	75	66	46	16	21	31	25	34	54	
		GFDL	65	45	25	20	45	60	35	55	75	
INVERTEBRATES	*B1*	*PCM1*	72	70	68	51	23	44	28	30	32	*7*
		GFDL	69	70	54	24	53	37	31	30	46	
	A2	*PCM1*	74	71	56	20	28	60	26	29	44	
		GFDL	76	59	29	26	48	73	24	41	71	
AMPHIBIANS	*B1*	*PCM1*	75	78	70	14	10	17	25	22	30	*12*
		GFDL	67	63	51	29	20	18	33	37	49	
	A2	*PCM1*	83	77	51	8	12	13	17	23	49	
		GFDL	73	44	21	16	21	23	27	56	79	
BIRDS	*B1*	*PCM1*	76	83	77	11	14	23	24	17	23	*29*
		GFDL	77	72	66	20	24	29	23	28	34	
	A2	*PCM1*	86	81	66	11	17	24	14	19	34	
		GFDL	80	59	41	20	20	39	20	41	59	
MAMMALS	*B1*	*PCM1*	68	80	70	11	14	21	32	20	30	*25*
		GFDL	68	63	59	15	18	24	32	37	41	
	A2	*PCM1*	84	75	54	13	18	18	16	25	46	
		GFDL	73	45	26	14	13	20	27	55	74	
REPTILES	*B1*	*PCM1*	68	77	70	25	26	46	32	23	30	*13*
		GFDL	72	66	60	34	30	40	28	34	40	
	A2	*PCM1*	77	70	54	32	33	46	23	30	46	
		GFDL	75	52	35	22	33	68	25	48	65	
SUITABILITY INFERENCE			**% REFUGIA decreasing**			**% EXPANSION increasing**			**% CONTRACTION increasing**			

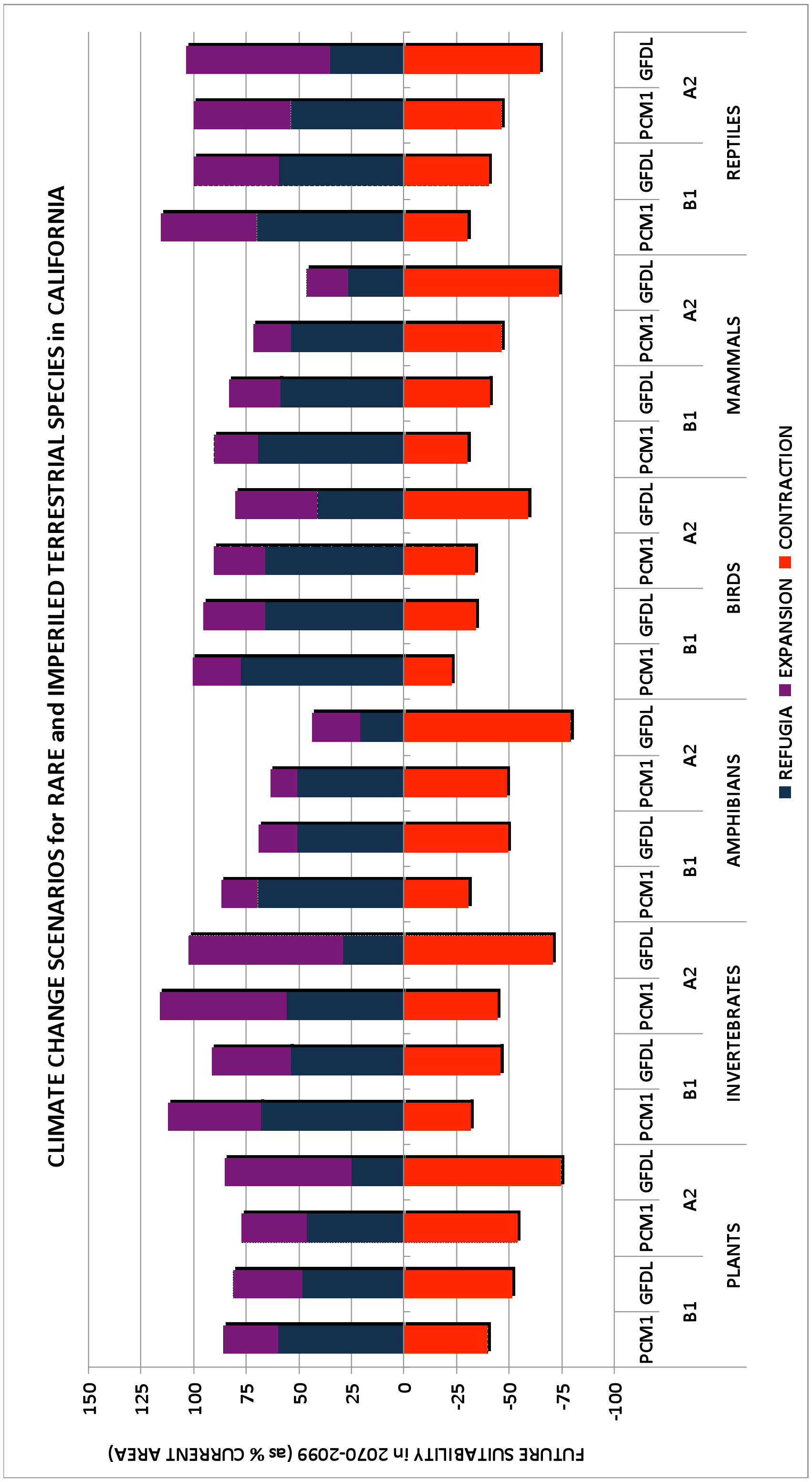


Figure 22. Statewide average projected changes in relative area of rare and imperiled species in California by 2070–2099 by emissions scenario and AOGCM

Biodiversity Valuation

Changes in biodiversity are likely to affect the economic value and impact of nearly all the ecosystems touched by these changes. In the previous sections, we showed how selected ecosystem changes might result in change in economic value and impact. We do not yet have a comprehensive understanding of the total impacts of climate change on biodiversity, ecosystem function, ecosystem and species distribution, nor ecosystem resilience, and such an analysis is well beyond the scope of this report.

Conclusion: Biodiversity

California is widely recognized for some of the highest levels of biodiversity globally (California Department of Fish and Game 2003), in part due to the presence of Mediterranean-type ecosystems known to harbor ~20% of global vascular plant species in only ~2.25% of the planet's land area (e.g., within California, Chile, the Mediterranean Basin, South Africa, and southwest Australia)(Hannah et al. 2007). Climate change is one of the most critical threats to biodiversity (Thomas et al. 2004; IPCC 2007). In California, observations of species migrations and range contractions driven by recent climate change are already well documented (Moritz et al. 2008; Monahan and Langham 2008; Kelly and Goulden 2008). This study re-enforces the intuitive, direct link proposed between the vulnerability of California's biodiversity and global emissions trajectories (Hayhoe et al. 2004). Across all broad taxonomic groups we surveyed, projections suggest increasing atmospheric greenhouse gases substantially increases negative biodiversity impacts. Forecasts of large-scale migrations, range contractions, and losses of historical refugia are common and widespread. It is unclear how climate impacts may affect current community composition, but some future assemblages may be entirely novel (Williams and Jackson 2007). Efforts to maintain future biodiversity in light of climate change will greatly benefit from the mapping and protection of: ecosystem services (Chan et al. 2006), speciation processes (Davis et al. 2008), potential future refugia (Loarie et al. 2008), and corridor networks to facilitate dispersal (Phillips et al. 2008). We stress the fundamental need to integrate science-based policy goals for climate change mitigation and climate change adaptation. California's ability to steward its unique biodiversity into the future will be highly dependent on the global greenhouse gas emissions trajectory.

3.0 Conclusions and Recommendations

3.1. Our Findings

Climate change will change the fundamental character, production, and distribution of the ecosystems upon which the economy of California has been built. Ecosystems contribute to the local microclimates of California, the production and distribution of water (without which populations cannot be sustained nor can they grow), statewide agriculture and ranching, tourism and national parks, recreation, and numerous other ecosystem services that protect homes, people, and businesses from floods, fire, drought, heat, cold, and pollution.

In this report we develop a basic framework for linking climate change to ecosystem function, production, and resilience and show how changes in ecosystems can affect the economic well-being of Californians (measured as the value ecosystems create beyond any costs of using or maintaining them) and the creation of economic activity (measured as market prices, revenues, and expenditures which in turn support jobs, salaries, and taxes.) Our scientific understanding of these links is still in the early stages of development. We use new models of ecosystem response to climate change and a review of the environmental and resource economics literature to show what the potential impact of these climate impacts might be.

California's economy is one of the world's largest, and much of this economy depends, in some way, on ecosystem health. As a result, we find that that large economic changes could result regardless of the climate change model or scenario considered. We show specifically how climate change could affect: (1) the ability of natural systems to store carbon, (2) the character and productivity of land cover especially as forage for cattle, and (3) precipitation and instream flows of water.

3.1.1. The Direct Market Impacts of Climate Change

Ideally, we would like to model the explicit links between climate change, ecosystems, and economic activity, including revenues, jobs, and salaries. As a case study, we show explicitly how climate-driven changes in land cover may affect the profits of cattle ranching in California. Under a variety of scenarios, we find that climate change could result in economic losses to the cattle industry of between $14 million and $191 million by year 2035 and between $22million and $312 million for the period 2070–2099 (Table 10). The approach we take for forage could be directly applied to a variety of agricultural sectors that depend on natural inputs that might be affected by climate change. Important candidates for future research include the contribution of pollinators to agricultural production, natural pest controls (including insects and birds), and the direct collection and sale of natural products (including wild mushrooms and botanicals.)

Our understanding of how ecosystem change will affect most marketed economic output is only partially developed. Nevertheless, we look at two examples of other uses of ecosystems that have direct market impacts: snow skiing and the recreational and commercial harvest of salmon. We find that more than $500 million of gross revenue currently is produced by the ski industry. These current and future revenues are at risk of serious decline because of the loss of natural snowpack that would result under most scenarios of predicted climate change. The exact relationship between snowpack and ski area revenues, however, is unknown for California and thus we are unable to estimate how much of these revenues will be lost because of climate change. Similarly, salmon harvest generates market impacts through the harvest and sale of salmon by commercial fishers. While the commercial salmon fishery has experienced significant declines in the past decade and the fishery in California was mostly closed for 2008, we still estimate annual revenues from commercially harvested salmon to be roughly $13 million (Table 10). Recreational fishing for salmon also generates revenues when anglers spend money on food, lodging, and supplies. Recreational salmon is an important part of the state's sportfishing industry. We estimate that recreational anglers spend up to $20 million annually, much of which could be lost due to climate change.

Table 10. Market-related economic impacts from climate-driven changes in ecosystem services. The table summarizes the current market value (gross revenues, profits, or spending) associated with the direct use of the ecosystem service or how future changes in the ecosystem service may affect market values (millions $).

	Contribution of Ecosystem Service to Market Value, Revenues, or Profits						
	Current ($ million)	2005-2034 ($ million)		2035-2064 ($ million)		2070-2099 ($ million)	
		low	high	low	high	low	high
Carbon (carbon trading market values)							
Low emissions scenario							
Warmer Wetter (PCM1)		19	146	327	2,541	1,021	7,926
Hotter Drier (GFDL and CCSM3)		-323	-2,524	-475	-13,145	-199	-11,769
High emissions scenario							
Warmer Wetter (PCM1)		115	891	304	2,357	815	6,327
Hotter Drier (GFDL and CCSM3)		-15	-2,950	-690	-11,223	-1,994	-22,129
Forage (contribution to profits)							
Low emissions scenario							
Warmer Wetter (PCM1)		-14	-47	-8	-26	-22	-74
Hotter Drier (GFDL)		-56	-191	-50	-170	-70	-235
High emissions scenario							
Warmer Wetter (PCM1)		15	50	8	-27	-50	-170
Hotter Drier (GFDL and CCSM3)		-36	-123	-62	-208	-92	-312
Skiing (expenditures by skiers)							
	500	-	-	-	-	-	-
Commercial Fishing (revenues)							
(gross revenues)	13	-	-	-	-	-	-
(net revenues, 2005/2006)	-5	-	-	-	-	-	-
Recreational Fishing (expenditures by anglers)							
	$20	-	-	-	-	-	-

Climate change also is likely to have a significant impact on the market cost of meeting new cap-and-trade goals for carbon emissions. Ecosystems are able to store carbon and, in many instances, may cost less per ton of carbon stored than other means of reducing atmospheric carbon or emissions. Climate change, however, could substantially change the ability of natural ecosystems to store carbon. Using market prices for carbon emissions, which have emerged from cap-and-trade systems and voluntary markets, we estimate that the impacts of climate change between 2005 and 2034 could result in a potential loss in carbon storage that would otherwise have had a market value of $325 million and $3 billion.

3.1.2. The Non-Market Impacts of Climate Change

Ecosystems generate value in addition to those values that appear in organized markets. In some cases, especially recreational services that depend on ecosystems, Californians enjoy an economic benefit that exceeds what they have to pay. These non-market values are important and changes in these values, due to climate change, represent real losses in the economic well-being of Californians. Indirectly, some changes in non-market values also can eventually reveal themselves in the value of homes near recreation sites, the cost of hotels, and other premiums that can be charged to recreationists. Much of this value, however, resides with the user. We estimate that the non-market value associated with snow skiing could exceed $174 million annually and that of recreational salmon angling could reach $20 million each year (Table 11). These estimates capture the non-market value of only two of the many types of outdoor recreation that could be affected by climate change. Similar non-market values are likely to accrue to birdwatchers, hikers, swimmers, divers, kayakers, and recreational anglers targeting other species. Non-market values, however, are not limited to recreation. The economic well-being of homeowners, land owners, outdoor workers, and even motorists who choose to drive on scenic byways depend on ecosystem conditions. All of these non-market values could change substantially due to climate change. Future research is needed to understand these potential changes and how recreational behavior, home values, and other non-market economic behavior will likely change due to climate change.

Table 11. Non-market impacts (changes in economic value) from climate-driven changes in ecosystem services. The table summarizes the current economic value (e.g., the social cost of carbon or the consumer surplus value of recreation) associated with the direct use of the ecosystem service or how future changes in the ecosystem service may affect economic value (e.g., the social cost of carbon, million $).

	Current ($ million)	2005-2034 ($ million)		2035-2064 ($ million)		2070-2099 ($ million)	
		low	high	low	high	low	high
Carbon (net social costs)							
Low emissions scenario							
Warmer Wetter (PCM1)		38	303	655	5,271	2,044	5,271
Hotter Drier (GFDL and CCSM3)		-646	5,236	-950	-27,269	-399	24,413
High emissions scenario							
Warmer Wetter (PCM1)		230	1,847	608	4,890	1,632	13,125
Hotter Drier (GFDL and CCSM3)		-31	6,119	-1,381	23,281	-3,992	45,904
Skiing (non-market recreational value)							
	174	-	-	-	-	-	-
Recreational Fishing (non-market recreational value)							
	20	-	-	-	-	-	-

3.1.3. The Social Cost of Climate Change

As described above, ecosystems generate market and non-market values. In the above examples, we examine cases in which these values are distinct and somewhat understood; in the case of non-market values we focus on the non-market value generated by the direct use of ecosystem outputs. In many cases, the market and non-market values of ecosystem services are difficult to parse. Many ecosystem services also have substantial non-use values, including cultural values, existence values, and option and bequest values.

A number of studies have attempted to estimate the social cost of climate change by considering the overall economic impact of increases atmospheric carbon dioxide. Obviously, these estimates are based on numerous assumptions and conclusions, many of which will change and become improved as a result of efforts like the current round of California Energy Commission's Public Interest Energy Research (PIER) studies on climate change impacts in California. Despite the exact magnitude of the economic effect of increased carbon in the atmosphere, the literature is clear that more atmospheric carbon will lead to more climate change which will, in turn, have economic impacts around the globe.

The affects of climate change on the ability of California ecosystems to store carbon could result in more carbon being released into the atmosphere. The impact of these changes differs substantially depending upon the climate change models and scenarios employed. Models that predict a wetter future climate indicate that California terrestrial ecosystems could increase in their carbon sequestering capabilities and could generate additional value to the world's economy of over to $300 million annually in the near future and as much as $18 billion annually by 2070. Other models of climate change, however, are far more pessimistic, predicting social costs from climate change of -$650 million to more than -$5 billion annually for the period 2005–2034 under scenario B1 using the CCSM3 model of climate change to as high as -$62 billion annually by the period 2070–2099.

Climate change also could make it more difficult, and thus more expensive, to meet societal goals that include ecosystem protection, conservation, and restoration—and also societal mandates to reduce pollutants, including atmospheric carbon. Because of local, state, and federal mandates, a number of California ecosystems are under active protection or restoration. Salmon habitat goals have been set by law and regulation. Similarly, other endangered and threatened species are required by law to be protected and managed. Marine ecosystems similarly are protected by a variety of state and federal laws. California recently implemented the nation's most ambitious law to cap the emissions of carbon in the state (AB32). Climate change could make these efforts more costly than would otherwise be the case. While we have not attempted to estimate these costs here, it is important to consider these potential differences in cost as an economic impact to the state—the extra funds required to meet these goals with climate change could have been invested elsewhere in the California economy.

3.2. What Do We Know About Climate Change and Ecosystem Services

California's diverse and vibrant economy is built around the equally diverse and vibrant ecosystems that dominated the California landscape during the nineteenth and twentieth centuries. Population centers grew up around the rich marine resources of San Francisco Bay, the fertile grazing lands of the Sacramento delta, and the comfortable Mediterranean climates of Southern California. America's fruit basket developed throughout the Central Valley and Central Coast where abundant water was joined with fertile soil and a climate that allowed for year-round growing seasons. Today, these and new areas continue to flourish—highly trained workers and engineers, scholars and computer scientists, and every day people continue to be drawn to California, in part for the outdoor lifestyle it offers. This desirable lifestyle, in turn, has kept home prices well above the national average—especially for coastal areas where outdoor recreational opportunities are abundant.

Now, the ecosystems upon which California has been built are likely to change significantly. At the same time, the sheer size and immobility of California's cities, farms, and industry are likely to change far less quickly. The ecosystem services that these cities, farmlands, and economies have come to take for granted will be substantially different in as little as 50 years. The economic well being of Californians and the California economy will also be different—the question is "in what way?"

Our research reveals that we know very little about the way ecosystems and the services they provide contribute to the economic wellbeing and productivity of California. Beyond a general knowledge of the overall importance of ecosystem services, we have only few and entirely unsystematic concrete examples of the value of these ecosystem services. Even more rudimentary is our understanding of how these ecosystem services will change due to climate change, how these changes will affect people and the California economy, and how the California economy will respond to these changes.

In the examples above, we highlight a small handful of ecosystem services for which we have some knowledge. Our findings show that even small changes in ecosystem productivity can have large changes in the value of the ecosystem service. In the case of the economic value of carbon sequestration—a service that helps keep climate change in check around the world—this value is large and is shared globally. In the case of natural forage, snow-based recreation, and salmon fishing, the impact is smaller in overall magnitude, but greater on its proportional impact on the sectors affected. It is important to remember that these examples were chosen not because of their expected change, but largely because of the availability of data. There are likely to be many other ecosystem services for which the effects of climate change will be larger and proportionately more important. For instance, consider the potential effect of climate change on: the ability of forests and natural vegetation to improve air quality and moderate urban and suburban temperatures; the ability of the ocean to sequester carbon, cool coastal areas (important to people and to agriculture), and provide seafood and recreation; the ability of montane and riparian forests to recharge groundwater and protect against flooding; the contribution of natural pollinators to agriculture, horticulture, and even home gardens; the list goes on.

Our research only scratches the surface of the potential impacts of climate change on ecosystem services and their contribution to the California economy. What we see is this:

> *We are largely ignorant of the value of ecosystem services to the California economy and even less knowledgeable about the ways in which climate change will affect these services and how California can best adapt to these changes.*

Until we close this gap in our understanding, we will be unable to fully comprehend or begin to mitigate the effects of climate change on Californians and the world's eighth largest economy.

3.3. Recommendations and Identification of Future Areas of Research

To better understand, avoid, and adapt to the impacts of climate change on California's economy, it is critical that we develop a better quantitative understanding of the links between climate change, ecosystems, and economic activity. The findings described above indicate that we know very little about the impacts of climate change on many critical ecosystems in California, including montane, riverine, estuarine, desert, chaparral, and marine ecosystems to name a few. While we are beginning to develop a literature on the economic value of many of these ecosystem services, our approach has not been systematic and has not been designed to address those ecosystem services that are most likely to change due to changes in climate. We need a research agenda that employs a strategic approach to understanding and modeling the impacts of climate change and other environmental change on ecosystem services in California.

We recommend that the state develop a long-term, statewide plan for developing integrated ecological and economic models of ecosystem services in California, with special emphasis on ecosystems likely to be affected by climate change. Specifically, we suggest the state:

- Create an interdisciplinary team (California Value of Ecosystem Assets Team – CAVEAT) to develop an interdisciplinary conceptual model of climate and ecosystem services change in California. A similar team has been created by the United States Environmental Protection Agency and the United States Department of Agriculture to better understand ecosystem services of particular importance to the Agency (the Ecosystem Services Research Program).
- Develop a research implementation plan to address research needs identified by the research team including:
    - New models linking climate change to ecosystem function and output
    - New environmental valuation studies to fill gaps in our understanding of the neutral climate future value of ecosystem services and predictive models regarding how these values and economic behaviors could change in the future.
- Develop, when appropriate, linked and integrated models of climate, ecosystem function, ecosystem services output, economic impacts and management options.

It is impossible to model all of the state's many ecosystem services in the near future. Nevertheless, the CAVEAT should develop a strategy that includes

- criteria for identifying ecosystems (including terrestrial, marine, and coastal ecosystems) that are most productive economically,
- ecosystems for which future change could result in the largest changes in economic value and impact,
- critical ecosystem linkages,
- critical climate linkages,
- critical management linkages, and
- means of encouraging the coordinated and interdisciplinary research needed to make the model functional and useful for policy.

We encourage California to make the CAVEAT framework, model and data open source—allowing for complete transparency in its development. We also encourage the state to exercise its authority and influence to encourage recipients of state-funded research on ecosystems and environmental and natural resource economics to show how their work will contribute to the model and to design research so that findings by state-funded research can better contribute to a more integrated and comprehensive understanding of the economic value of California ecosystems. For example, much existing research cannot be easily integrated into an interdisciplinary model because the spatial and temporal scales at which data are collected are not synchronized or standardized. Such standardization would greatly facilitate the use of data from different projects.

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5.0 Glossary

A2	IPCC high greenhouse gas emissions scenario
AOGCM	Atmospheric-oceanic global climate models
AUM	Animal Unit Month
B1	IPCC low greenhouse gas emissions scenario
BCSD	bias correction and spatial disaggregation method
BLM	Bureau of Land Management
C3 and C4 grasses	C3 and C4 carbon fixation

CCAR	California Climate Action Registry
CCSM3	Community Climate System Model 3
CDF	California Department of Forestry and Fire Protection
CNDDB	California Natural Diversity Database
DGVM	Dynamic Global Vegetation Model
DM	Dry Matter
GFDL	Geophysical Fluid Dynamics Laboratory
GRANK	Global Rank
SRANK	State Rank
ESRI	Environmental Systems Research Institute
IPCC	Intergovernmental Panel on Climate Change
MA	Millennium Ecosystem Assessment
MC1	A dynamic vegetation model developed by the US Forest Service
MEA	Millennium Ecosystem Assessment
NCAR	National Center for Atmospheric Research
PCM	Parallel Climate Model
NRCS	Natural Resources Conservation Service
STATSGO	State Soil Geographic (soil data)
PRISM	Parameter Elevation Regressions on Independent Slopes Model
SDM	Species distribution model
SP	State Park
SWE	Snow water equivalent
UCSD	University of California San Diego
USDA	United States Department of Agriculture
VIC	Variable Infiltration Capacity model

Appendix A

California Plant Cover Change in California 2005–2099

Appendix A. California Plant Cover Change in California 2005–2099

				Model			
Vegetation Type	Emissions Scenario	Time Period	Base (Ha)	PCM1		GFDL	
				(Ha)	% Difference from Base	(Ha)	% Difference from Base
Conifer Forest	B1	2005 - 2034	10,265,694	10,127,383	-1%	9,650,981	-6%
		2035 - 2064	10,542,314	10,265,694	-3%	8,913,327	-15%
		2070 - 2099	10,035,177	9,374,361	-7%	8,068,098	-20%
	A2	2005 - 2034	10,265,694	9,989,073	-3%	9,528,039	-7%
		2035 - 2064	10,542,314	9,912,234	-6%	8,605,971	-18%
		2070 - 2099	10,035,177	9,082,373	-9%	5,271,157	-47%
Conifer Woodland	B1	2005 - 2034	568,609	583,977	3%	583,977	3%
		2035 - 2064	614,712	660,816	8%	476,402	-23%
		2070 - 2099	737,655	537,873	-27%	414,931	-44%
	A2	2005 - 2034	568,609	630,080	11%	445,666	-22%
		2035 - 2064	614,712	768,390	25%	599,344	-3%
		2070 - 2099	737,655	507,138	-31%	261,253	-65%
Desert Shrub	B1	2005 - 2034	10,081,280	9,697,085	-4%	12,002,256	19%
		2035 - 2064	10,096,648	10,911,141	8%	11,602,693	15%
		2070 - 2099	10,096,648	10,649,889	5%	12,955,059	28%
	A2	2005 - 2034	10,081,280	10,818,935	7%	11,510,486	14%
		2035 - 2064	10,096,648	10,834,302	7%	11,694,899	16%
		2070 - 2099	10,096,648	9,405,097	-7%	13,001,163	29%
Hardwood Forest	B1	2005 - 2034	3,350,181	3,150,400	-6%	3,073,561	-8%
		2035 - 2064	4,072,468	3,442,388	-15%	4,072,468	0%
		2070 - 2099	3,811,216	3,795,848	0%	4,441,296	17%
	A2	2005 - 2034	3,350,181	2,858,412	-15%	3,626,802	8%
		2035 - 2064	4,072,468	3,780,480	-7%	3,949,526	-3%
		2070 - 2099	3,811,216	4,441,296	17%	4,133,939	8%
Hardwood Woodland	B1	2005 - 2034	3,488,492	3,811,216	9%	4,149,307	19%
		2035 - 2064	2,965,986	4,118,572	39%	4,533,502	53%
		2070 - 2099	3,196,503	4,210,779	32%	3,826,583	20%
	A2	2005 - 2034	3,488,492	4,103,204	18%	3,934,158	13%
		2035 - 2064	2,965,986	3,780,480	27%	4,564,238	54%
		2070 - 2099	3,196,503	3,626,802	13%	3,165,768	-1%
Herbaceous	B1	2005 - 2034	6,792,570	6,838,673	1%	4,979,169	-27%
		2035 - 2064	6,454,478	5,716,823	-11%	4,917,698	-24%
		2070 - 2099	6,562,053	6,193,225	-6%	4,010,997	-39%
	A2	2005 - 2034	6,792,570	6,900,144	2%	5,762,927	-15%
		2035 - 2064	6,454,478	6,377,639	-1%	4,287,618	-34%
		2070 - 2099	6,562,053	5,593,881	-15%	4,318,353	-34%
Shrub	B1	2005 - 2034	5,885,869	6,223,961	6%	6,024,179	2%
		2035 - 2064	5,701,456	5,332,628	-6%	5,962,708	5%
		2070 - 2099	5,993,444	5,716,823	-5%	6,761,834	13%
	A2	2005 - 2034	5,885,869	5,132,847	-13%	5,655,352	-4%
		2035 - 2064	5,701,456	5,009,904	-12%	6,777,202	19%
		2070 - 2099	5,993,444	7,822,213	31%	10,327,165	72%

Appendix B

Carbon Sequestration for All Ecosystem Stocks

Appendix B. Carbon Sequestration for All Ecosystem Stocks

Table B1. Amount of Carbon (in teragrams, Tg) for all six stocks combined (aboveground live tree and grass, and dead carbon and belowground tree and grass, and dead carbon) by time period

Model	Scenario	Average Tg	Time Period	Difference from Base (%)
base	base	5604	2005 - 2034	0%
ccsm3	a2	5586	2005 - 2034	0%
ccsm3	b1	5582	2005 - 2034	0%
gfdl	a2	5618	2005 - 2034	0%
gfdl	b1	5546	2005 - 2034	-1%
pcm1	a2	5634	2005 - 2034	1%
pcm1	b1	5607	2005 - 2034	0%
base	base	5572	2035 - 2064	0%
ccsm3	a2	5447	2035 - 2064	-2%
ccsm3	b1	5421	2035 - 2064	-3%
gfdl	a2	5510	2035 - 2064	-1%
gfdl	b1	5485	2035 - 2064	-2%
pcm1	a2	5657	2035 - 2064	2%
pcm1	b1	5635	2035 - 2064	1%
base	base	5476	2070 - 2099	0%
ccsm3	a2	5230	2070 - 2099	-5%
ccsm3	b1	5308	2070 - 2099	-3%
gfdl	a2	5268	2070 - 2099	-4%
gfdl	b1	5421	2070 - 2099	-1%
pcm1	a2	5706	2070 - 2099	4%
pcm1	b1	5659	2070 - 2099	3%

Table B2. Amount of carbon (Tg) by stock, time period, model and scenario showing difference from base

Model	Scenario	Average Tg	Time Period	C Stock	Difference from Base (%)
base	base	878.99	2005 - 2034	max aboveground dead carbon	0%
ccsm3	a2	885.61	2005 - 2034	max aboveground dead carbon	1%
ccsm3	b1	881.80	2005 - 2034	max aboveground dead carbon	0%
gfdl	a2	879.29	2005 - 2034	max aboveground dead carbon	0%
gfdl	b1	875.27	2005 - 2034	max aboveground dead carbon	0%
pcm1	a2	879.64	2005 - 2034	max aboveground dead carbon	0%
pcm1	b1	877.22	2005 - 2034	max aboveground dead carbon	0%
base	base	12.22	2005 - 2034	max aboveground live grass carbon	0%
ccsm3	a2	12.33	2005 - 2034	max aboveground live grass carbon	1%
ccsm3	b1	11.76	2005 - 2034	max aboveground live grass carbon	-4%
gfdl	a2	11.56	2005 - 2034	max aboveground live grass carbon	-5%
gfdl	b1	10.94	2005 - 2034	max aboveground live grass carbon	-11%
pcm1	a2	12.54	2005 - 2034	max aboveground live grass carbon	3%
pcm1	b1	12.70	2005 - 2034	max aboveground live grass carbon	4%
base	base	1025.30	2005 - 2034	max aboveground live tree carbon	0%
ccsm3	a2	992.22	2005 - 2034	max aboveground live tree carbon	-3%
ccsm3	b1	997.22	2005 - 2034	max aboveground live tree carbon	-3%
gfdl	a2	1023.97	2005 - 2034	max aboveground live tree carbon	0%
gfdl	b1	997.00	2005 - 2034	max aboveground live tree carbon	-3%
pcm1	a2	1035.28	2005 - 2034	max aboveground live tree carbon	1%
pcm1	b1	1026.93	2005 - 2034	max aboveground live tree carbon	0%
base	base	3494.97	2005 - 2034	max belowground dead carbon	0%
ccsm3	a2	3507.67	2005 - 2034	max belowground dead carbon	0%
ccsm3	b1	3506.70	2005 - 2034	max belowground dead carbon	0%
gfdl	a2	3513.77	2005 - 2034	max belowground dead carbon	1%
gfdl	b1	3484.27	2005 - 2034	max belowground dead carbon	0%
pcm1	a2	3513.39	2005 - 2034	max belowground dead carbon	1%
pcm1	b1	3499.67	2005 - 2034	max belowground dead carbon	0%
base	base	56.39	2005 - 2034	max belowground live grass carbon	0%
ccsm3	a2	57.20	2005 - 2034	max belowground live grass carbon	1%
ccsm3	b1	54.37	2005 - 2034	max belowground live grass carbon	-4%
gfdl	a2	55.88	2005 - 2034	max belowground live grass carbon	-1%
gfdl	b1	51.43	2005 - 2034	max belowground live grass carbon	-9%
pcm1	a2	57.93	2005 - 2034	max belowground live grass carbon	3%
pcm1	b1	57.34	2005 - 2034	max belowground live grass carbon	2%
base	base	136.43	2005 - 2034	max belowground live tree carbon	0%
ccsm3	a2	131.33	2005 - 2034	max belowground live tree carbon	-4%
ccsm3	b1	130.57	2005 - 2034	max belowground live tree carbon	-4%
gfdl	a2	133.70	2005 - 2034	max belowground live tree carbon	-2%
gfdl	b1	127.43	2005 - 2034	max belowground live tree carbon	-7%
pcm1	a2	134.76	2005 - 2034	max belowground live tree carbon	-1%
pcm1	b1	133.22	2005 - 2034	max belowground live tree carbon	-2%
base	base	861.46	2035 - 2064	max aboveground dead carbon	0%
ccsm3	a2	854.50	2035 - 2064	max aboveground dead carbon	-1%

ccsm3	b1	857.67	2035 - 2064	max aboveground dead carbon	0%
gfdl	a2	862.45	2035 - 2064	max aboveground dead carbon	0%
gfdl	b1	851.07	2035 - 2064	max aboveground dead carbon	-1%
pcm1	a2	869.47	2035 - 2064	max aboveground dead carbon	1%
pcm1	b1	870.49	2035 - 2064	max aboveground dead carbon	1%
base	base	11.68	2035 - 2064	max aboveground live grass carbon	0%
ccsm3	a2	12.33	2035 - 2064	max aboveground live grass carbon	6%
ccsm3	b1	13.12	2035 - 2064	max aboveground live grass carbon	12%
gfdl	a2	11.30	2035 - 2064	max aboveground live grass carbon	-3%
gfdl	b1	11.02	2035 - 2064	max aboveground live grass carbon	-6%
pcm1	a2	12.34	2035 - 2064	max aboveground live grass carbon	6%
pcm1	b1	11.75	2035 - 2064	max aboveground live grass carbon	1%
base	base	1028.18	2035 - 2064	max aboveground live tree carbon	0%
ccsm3	a2	902.34	2035 - 2064	max aboveground live tree carbon	-12%
ccsm3	b1	880.79	2035 - 2064	max aboveground live tree carbon	-14%
gfdl	a2	968.14	2035 - 2064	max aboveground live tree carbon	-6%
gfdl	b1	986.86	2035 - 2064	max aboveground live tree carbon	-4%
pcm1	a2	1054.62	2035 - 2064	max aboveground live tree carbon	3%
pcm1	b1	1056.68	2035 - 2064	max aboveground live tree carbon	3%
base	base	3477.13	2035 - 2064	max belowground dead carbon	0%
ccsm3	a2	3491.85	2035 - 2064	max belowground dead carbon	0%
ccsm3	b1	3484.98	2035 - 2064	max belowground dead carbon	0%
gfdl	a2	3487.50	2035 - 2064	max belowground dead carbon	0%
gfdl	b1	3453.74	2035 - 2064	max belowground dead carbon	-1%
pcm1	a2	3529.66	2035 - 2064	max belowground dead carbon	2%
pcm1	b1	3506.85	2035 - 2064	max belowground dead carbon	1%
base	base	53.41	2035 - 2064	max belowground live grass carbon	0%
ccsm3	a2	57.23	2035 - 2064	max belowground live grass carbon	7%
ccsm3	b1	59.76	2035 - 2064	max belowground live grass carbon	12%
gfdl	a2	52.76	2035 - 2064	max belowground live grass carbon	-1%
gfdl	b1	51.97	2035 - 2064	max belowground live grass carbon	-3%
pcm1	a2	56.49	2035 - 2064	max belowground live grass carbon	6%
pcm1	b1	53.46	2035 - 2064	max belowground live grass carbon	0%
base	base	140.05	2035 - 2064	max belowground live tree carbon	0%
ccsm3	a2	128.52	2035 - 2064	max belowground live tree carbon	-8%
ccsm3	b1	124.37	2035 - 2064	max belowground live tree carbon	-11%
gfdl	a2	127.87	2035 - 2064	max belowground live tree carbon	-9%
gfdl	b1	130.02	2035 - 2064	max belowground live tree carbon	-7%
pcm1	a2	134.60	2035 - 2064	max belowground live tree carbon	-4%
pcm1	b1	135.30	2035 - 2064	max belowground live tree carbon	-3%
base	base	864.12	2070 - 2099	max aboveground dead carbon	0%
ccsm3	a2	821.38	2070 - 2099	max aboveground dead carbon	-5%
ccsm3	b1	807.10	2070 - 2099	max aboveground dead carbon	-7%
gfdl	a2	833.97	2070 - 2099	max aboveground dead carbon	-3%
gfdl	b1	832.82	2070 - 2099	max aboveground dead carbon	-4%
pcm1	a2	883.87	2070 - 2099	max aboveground dead carbon	2%
pcm1	b1	864.25	2070 - 2099	max aboveground dead carbon	0%
base	base	11.75	2070 - 2099	max aboveground live grass carbon	0%
ccsm3	a2	14.39	2070 - 2099	max aboveground live grass carbon	22%
ccsm3	b1	13.43	2070 - 2099	max aboveground live grass carbon	14%

gfdl	a2	13.07	2070 - 2099	max aboveground live grass carbon	11%
gfdl	b1	11.62	2070 - 2099	max aboveground live grass carbon	-1%
pcm1	a2	14.29	2070 - 2099	max aboveground live grass carbon	22%
pcm1	b1	12.75	2070 - 2099	max aboveground live grass carbon	8%
base	base	951.94	2070 - 2099	max aboveground live tree carbon	0%
ccsm3	a2	703.81	2070 - 2099	max aboveground live tree carbon	-26%
ccsm3	b1	819.98	2070 - 2099	max aboveground live tree carbon	-14%
gfdl	a2	778.36	2070 - 2099	max aboveground live tree carbon	-18%
gfdl	b1	934.61	2070 - 2099	max aboveground live tree carbon	-2%
pcm1	a2	1022.89	2070 - 2099	max aboveground live tree carbon	7%
pcm1	b1	1040.82	2070 - 2099	max aboveground live tree carbon	9%
base	base	3457.82	2070 - 2099	max belowground dead carbon	0%
ccsm3	a2	3502.15	2070 - 2099	max belowground dead carbon	1%
ccsm3	b1	3480.03	2070 - 2099	max belowground dead carbon	1%
gfdl	a2	3467.81	2070 - 2099	max belowground dead carbon	0%
gfdl	b1	3459.08	2070 - 2099	max belowground dead carbon	0%
pcm1	a2	3585.48	2070 - 2099	max belowground dead carbon	4%
pcm1	b1	3548.28	2070 - 2099	max belowground dead carbon	3%
base	base	53.71	2070 - 2099	max belowground live grass carbon	0%
ccsm3	a2	65.07	2070 - 2099	max belowground live grass carbon	21%
ccsm3	b1	61.29	2070 - 2099	max belowground live grass carbon	14%
gfdl	a2	58.66	2070 - 2099	max belowground live grass carbon	9%
gfdl	b1	55.98	2070 - 2099	max belowground live grass carbon	4%
pcm1	a2	64.74	2070 - 2099	max belowground live grass carbon	21%
pcm1	b1	59.72	2070 - 2099	max belowground live grass carbon	11%
base	base	137.10	2070 - 2099	max belowground live tree carbon	0%
ccsm3	a2	123.19	2070 - 2099	max belowground live tree carbon	-10%
ccsm3	b1	126.64	2070 - 2099	max belowground live tree carbon	-8%
gfdl	a2	115.84	2070 - 2099	max belowground live tree carbon	-16%
gfdl	b1	126.70	2070 - 2099	max belowground live tree carbon	-8%
pcm1	a2	135.24	2070 - 2099	max belowground live tree carbon	-1%
pcm1	b1	133.56	2070 - 2099	max belowground live tree carbon	-3%

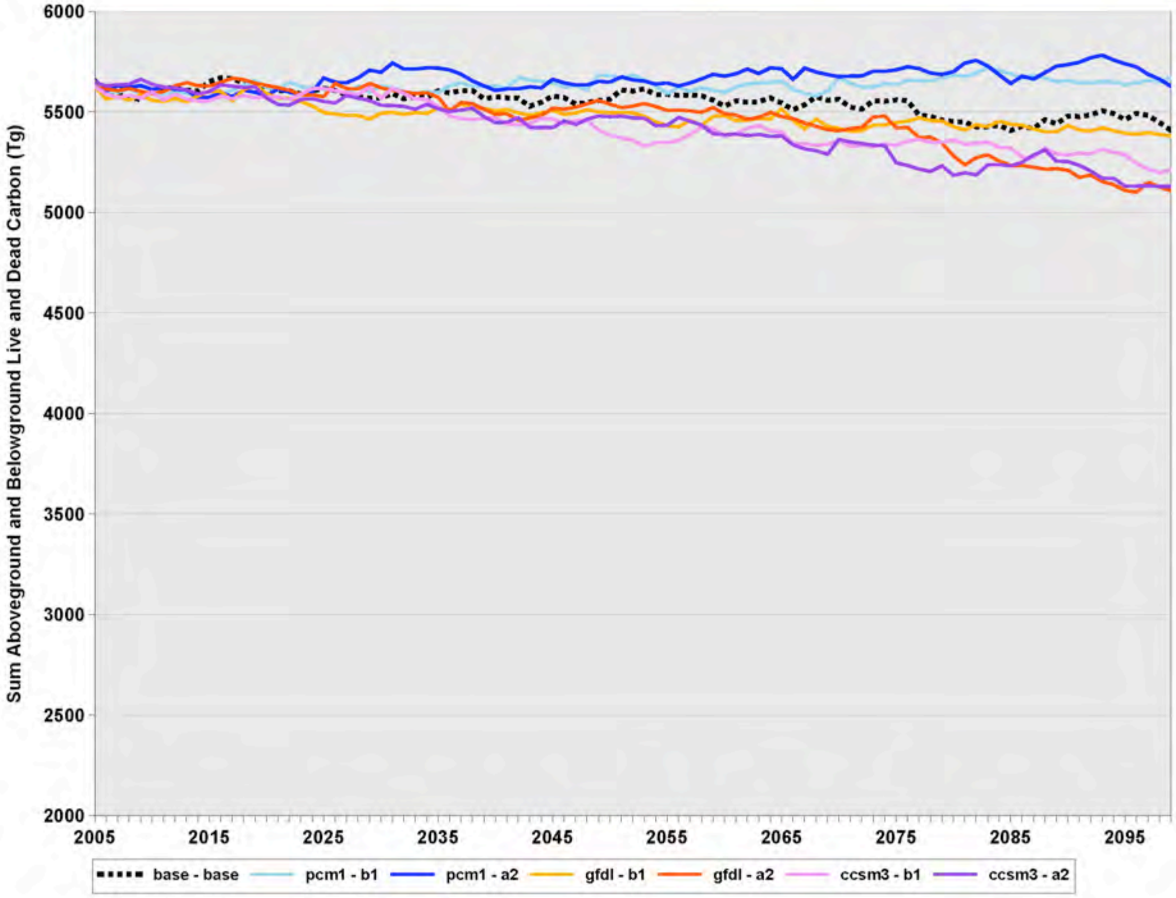


Figure B1. Yearly carbon storage in all stocks combined by model and scenario

Appendix C

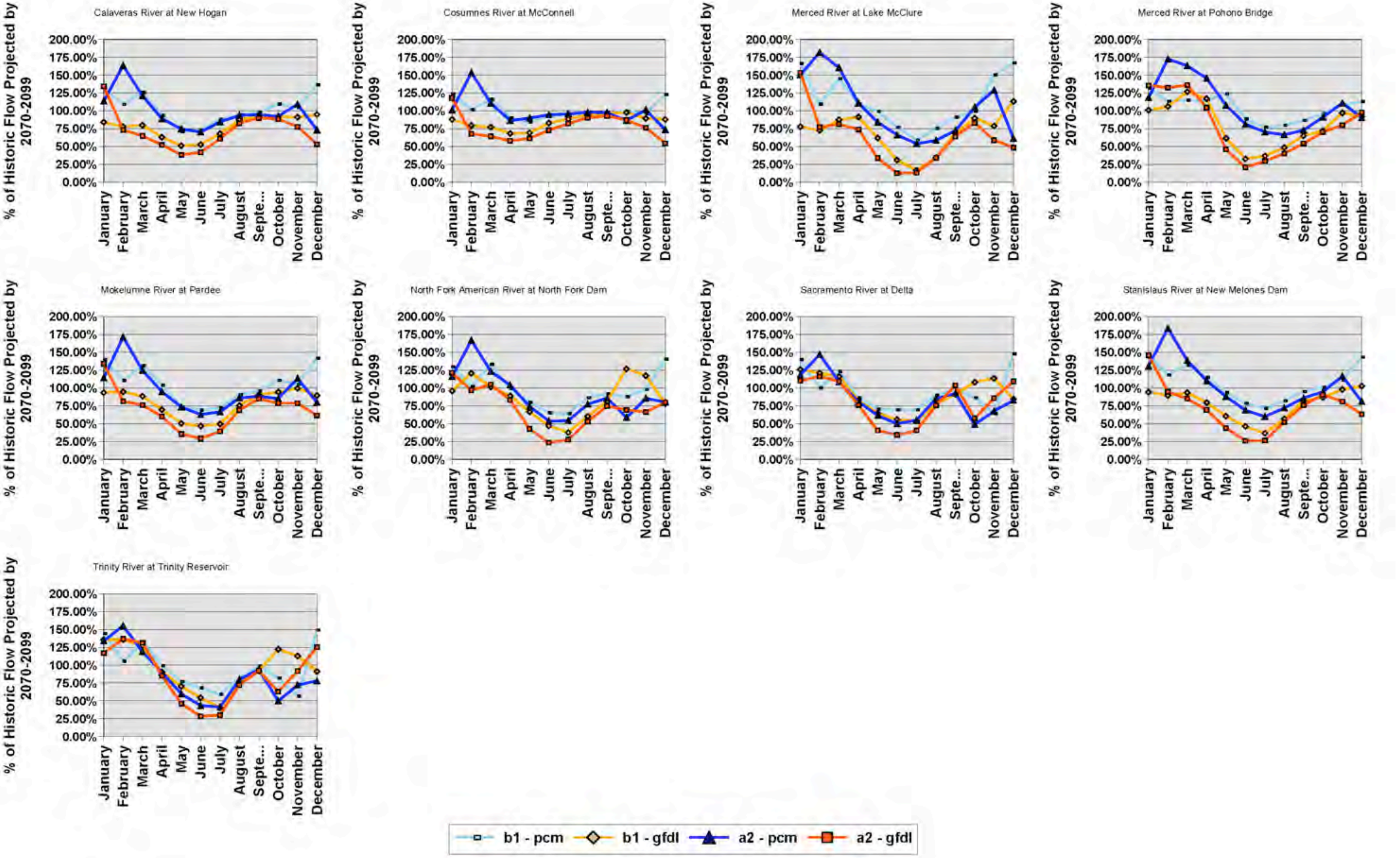
Stream Flow by Time Period, by Model and Scenario by River Annual Sums and Difference from Historical Flows by Model, Scenarios, Month, and Time Period

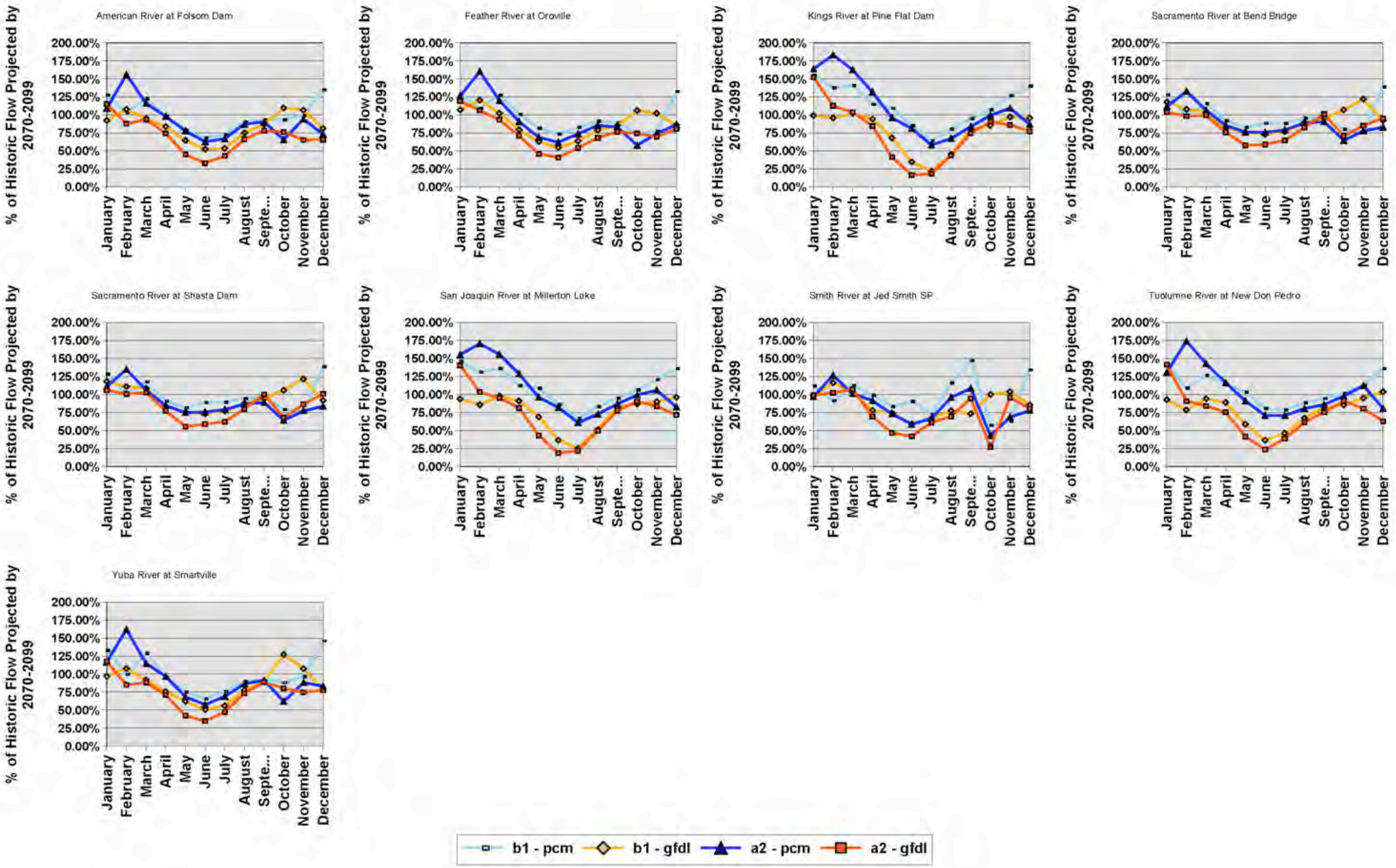
Appendix C: Stream flow by time period, by model and scenario by river annual sums and difference from historical flows by model, scenarios, month, and time period

Station	Sce- nario	AO- GCM	Avg Spring Flow (cfs) 1961 - 1990	Avg Spring Flow (cfs) 2005 - 2034	Avg Spring Flow (cfs) 2035 - 2064	Avg Spring Flow (cfs) 2070 - 2099	Difference in Avg Spring Flow (2070-2099 -Hist)	% Diff (2070-2099) - Hist)
American River at Folsom Dam	B1	PCM1	6,120	6,548	6,537	5,774	-346	-6%
American River at Folsom Dam	B1	GFDL	5,941	5,460	5,199	4,512	-1,429	-24%
American River at Folsom Dam	A2	PCM1	6,256	6,211	5,852	5,711	-545	-9%
American River at Folsom Dam	A2	GFDL	6,090	5,572	5,065	3,913	-2,177	-36%
Calaveras River at New Hogan	B1	PCM1	892	985	920	853	-39	-4%
Calaveras River at New Hogan	B1	GFDL	874	755	675	555	-319	-37%
Calaveras River at New Hogan	A2	PCM1	911	936	807	847	-64	-7%
Calaveras River at New Hogan	A2	GFDL	900	768	695	457	-443	-49%
Cosumnes River at McConnell	B1	PCM1	1,414	1,550	1,536	1,405	-9	-1%
Cosumnes River at McConnell	B1	GFDL	1,435	1,243	1,184	1,056	-379	-26%
Cosumnes River at McConnell	A2	PCM1	1,449	1,458	1,272	1,410	-40	-3%
Cosumnes River at McConnell	A2	GFDL	1,425	1,296	1,190	896	-529	-37%
Feather River at Oroville	B1	PCM1	8,864	10,056	10,177	8,761	-103	-1%
Feather River at Oroville	B1	GFDL	8,739	8,313	7,647	6,705	-2,033	-23%
Feather River at Oroville	A2	PCM1	9,330	9,076	8,695	8,254	-1,076	-12%
Feather River at Oroville	A2	GFDL	8,926	8,246	7,567	5,817	-3,109	-35%
Kings River at Pine Flat Dam	B1	PCM1	4,604	5,579	4,751	4,942	338	7%
Kings River at Pine Flat Dam	B1	GFDL	4,457	4,346	3,948	2,939	-1,518	-34%
Kings River at Pine Flat Dam	A2	PCM1	4,704	5,103	4,943	5,025	321	7%
Kings River at Pine Flat Dam	A2	GFDL	4,640	4,075	4,059	2,284	-2,357	-51%
Merced River at Lake McClure	B1	PCM1	2,675	3,099	2,726	2,790	116	4%
Merced River at Lake McClure	B1	GFDL	2,528	2,445	2,187	1,609	-919	-36%
Merced River at Lake McClure	A2	PCM1	2,716	2,804	2,614	2,665	-51	-2%
Merced River at Lake McClure	A2	GFDL	2,594	2,332	2,292	1,137	-1,457	-56%
Merced River at Pohono Bridge	B1	PCM1	1,017	1,233	1,003	1,123	106	10%
Merced River at Pohono Bridge	B1	GFDL	967	996	851	610	-358	-37%
Merced River at Pohono Bridge	A2	PCM1	1,028	1,098	1,012	1,107	79	8%
Merced River at Pohono Bridge	A2	GFDL	989	881	883	521	-468	-47%
Mokelumne River at Pardee	B1	PCM1	1,838	2,038	1,895	1,773	-65	-4%
Mokelumne River at Pardee	B1	GFDL	1,802	1,590	1,410	1,161	-641	-36%
Mokelumne River at Pardee	A2	PCM1	1,899	1,884	1,700	1,724	-175	-9%

Mokelumne River at Pardee	A2	GFDL	1,808	1,608	1,425	919	-888	-49%
North Fork American River at North Fork Dam	B1	PCM1	1,424	1,516	1,536	1,347	-76	-5%
North Fork American River at North Fork Dam	B1	GFDL	1,361	1,288	1,214	1,035	-326	-24%
North Fork American River at North Fork Dam	A2	PCM1	1,463	1,443	1,389	1,297	-166	-11%
North Fork American River at North Fork Dam	A2	GFDL	1,406	1,309	1,179	892	-514	-37%
Sacramento River at Bend Bridge	B1	PCM1	16,095	17,544	18,618	15,636	-459	-3%
Sacramento River at Bend Bridge	B1	GFDL	15,292	15,043	14,212	13,197	-2,096	-14%
Sacramento River at Bend Bridge	A2	PCM1	16,562	15,673	15,246	14,700	-1,862	-11%
Sacramento River at Bend Bridge	A2	GFDL	15,581	15,369	12,956	11,902	-3,678	-24%
Sacramento River at Delta	B1	PCM1	1,465	1,540	1,674	1,351	-114	-8%
Sacramento River at Delta	B1	GFDL	1,380	1,359	1,256	1,174	-206	-15%
Sacramento River at Delta	A2	PCM1	1,491	1,372	1,328	1,203	-289	-19%
Sacramento River at Delta	A2	GFDL	1,406	1,399	1,131	1,012	-394	-28%
Sacramento River at Shasta Dam	B1	PCM1	12,024	13,254	13,873	11,682	-341	-3%
Sacramento River at Shasta Dam	B1	GFDL	11,422	11,374	10,627	10,032	-1,390	-12%
Sacramento River at Shasta Dam	A2	PCM1	12,353	11,773	11,444	10,860	-1,492	-12%
Sacramento River at Shasta Dam	A2	GFDL	11,657	11,392	9,680	9,003	-2,654	-23%
San Joaquin River at Millerton Lake	B1	PCM1	4,976	6,032	5,121	5,324	348	7%
San Joaquin River at Millerton Lake	B1	GFDL	4,816	4,696	4,270	3,214	-1,601	-33%
San Joaquin River at Millerton Lake	A2	PCM1	5,082	5,514	5,286	5,447	365	7%
San Joaquin River at Millerton Lake	A2	GFDL	5,009	4,399	4,403	2,516	-2,492	-50%
Smith River at Jed Smith SP	B1	PCM1	4,135	4,249	5,041	4,152	18	0%
Smith River at Jed Smith SP	B1	GFDL	4,106	3,455	4,013	3,480	-626	-15%
Smith River at Jed Smith SP	A2	PCM1	4,229	4,051	3,999	3,740	-489	-12%
Smith River at Jed Smith SP	A2	GFDL	4,169	4,132	3,489	3,197	-971	-23%
Stanislaus River at New Melones Dam	B1	PCM1	2,170	2,500	2,220	2,227	57	3%
Stanislaus River at New Melones Dam	B1	GFDL	2,078	2,039	1,738	1,400	-678	-33%
Stanislaus River at New Melones Dam	A2	PCM1	2,229	2,304	2,125	2,192	-37	-2%
Stanislaus River at New Melones Dam	A2	GFDL	2,116	1,921	1,859	1,108	-1,008	-48%
Trinity River at Trinity Reservoir	B1	PCM1	2,797	2,948	3,151	2,687	-110	-4%
Trinity River at Trinity Reservoir	B1	GFDL	2,553	2,624	2,481	2,232	-321	-13%
Trinity River at Trinity Reservoir	A2	PCM1	2,866	2,578	2,525	2,298	-567	-20%
Trinity River at Trinity Reservoir	A2	GFDL	2,586	2,734	2,233	1,955	-631	-24%
Tuolumne River at New Don Pedro	B1	PCM1	4,697	5,480	4,737	4,919	223	5%
Tuolumne River at New Don Pedro	B1	GFDL	4,551	4,481	3,783	2,931	-1,620	-36%

Tuolumne River at New Don Pedro	A2	PCM1	4,798	4,969	4,528	4,781	-17	0%
Tuolumne River at New Don Pedro	A2	GFDL	4,626	4,031	3,979	2,353	-2,273	-49%
Yuba River at Smartville	B1	PCM1	6,521	7,051	7,348	6,151	-370	-6%
Yuba River at Smartville	B1	GFDL	6,279	5,809	5,472	4,499	-1,781	-28%
Yuba River at Smartville	A2	PCM1	6,820	6,458	6,185	5,930	-890	-13%
Yuba River at Smartville	A2	GFDL	6,536	5,981	5,285	3,989	-2,547	-39%


Calaveras River at New Hogan
Cosumnes River at McConnell
Merced River at Lake McClure
Merced River at Pohono Bridge
Mokelumne River at Pardee
North Fork American River at North Fork Dam
Sacramento River at Delta
Stanislaus River at New Melones Dam
Trinity River at Trinity Reservoir
% of Historic Flow Projected by 2070-2099
200.00%
175.00%
150.00%
125.00%
100.00%
75.00%
50.00%
25.00%
0.00%
January
February
March
April
May
June
July
August
Septe...
October
November
December
b1 - pcm
b1 - gfdl
a2 - pcm
a2 - gfdl


American River at Folsom Dam
Feather River at Oroville
Kings River at Pine Flat Dam
Sacramento River at Bend Bridge
Sacramento River at Shasta Dam
San Joaquin River at Millerton Lake
Smith River at Jed Smith SP
Tuolumne River at New Don Pedro
Yuba River at Smartville
% of Historic Flow Projected by 2070-2099
200.00%
175.00%
150.00%
125.00%
100.00%
75.00%
50.00%
25.00%
0.00%
January
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May
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December
b1 - pcm
b1 - gfdl
a2 - pcm
a2 - gfdl

Appendix D

California Species Analyzed in the Biodiversity Section

Appendix D

California Species Analyzed in the Biodiversity Section

The table below lists the taxonomic grouping (Taxa), the scientific names, and the common names as presented in the California Natural Diversity Database; the global and state conservation ranking (GRANK and SRANK); and the number of unique 12 km grid cells in which the species was found between 1960 to the present (OBS unique).

TAXA	Scientific Name	Common Name	GRANK	SRANK	OBS unique
amphibian	Ambystoma californiense	California tiger salamander	G2G3	S2S3	156
amphibian	Ascaphus truei	western tailed frog	G4	S2S3	86
amphibian	Batrachoseps robustus	Kern slender salamander	G2	S2	12
amphibian	Bufo californicus	arroyo toad	G2G3	S2S3	51
amphibian	Bufo canorus	Yosemite toad	G2	S2	39
amphibian	Plethodon stormi	Siskiyou Mountains salamander	G2G3	S1S2	11
amphibian	Rana aurora aurora	northern red-legged frog	G4T4	S2?	22
amphibian	Rana boylii	foothill yellow-legged frog	G3	S2S3	229
amphibian	Rana draytonii	California red-legged frog	G4T2T3	S2S3	171
amphibian	Rana muscosa	Sierra Madre yellow-legged frog	G1	S1	29
amphibian	Rana sierrae	Sierra Nevada yellow-legged frog	G1	S1	71
amphibian	Rhyacotriton variegatus	southern torrent salamander	G3G4	S2S3	54
bird	Agelaius tricolor	tricolored blackbird	G2G3	S2	199
bird	Aimophila ruficeps canescens	southern California rufous-crowned sparrow	G5T2T4	S2S3	52
bird	Ammodramus savannarum	grasshopper sparrow	G5	S2	16
bird	Amphispiza belli belli	Bell's sage sparrow	G5T2T4	S2?	26
bird	Athene cunicularia	burrowing owl	G4	S2	304
bird	Branta hutchinsii leucopareia	cackling (=Aleutian Canada) goose	G5T4	S2	11
bird	Buteo swainsoni	Swainson's hawk	G5	S2	219
bird	Charadrius alexandrinus nivosus	western snowy plover	G4T3	S2	48
bird	Charadrius montanus	mountain plover	G2	S2?	24
bird	Coccyzus americanus occidentalis	western yellow-billed cuckoo	G5T3Q	S1	40
bird	Cypseloides niger	black swift	G4	S2	23
bird	Dendroica petechia brewsteri	yellow warbler	G5T3?	S2	34
bird	Empidonax traillii	willow flycatcher	G5	S1S2	56
bird	Empidonax traillii extimus	southwestern willow flycatcher	G5T1T2	S1	30
bird	Falco peregrinus anatum	American peregrine falcon	G4T3	S2	22
bird	Grus canadensis tabida	greater sandhill crane	G5T4	S2	120
bird	Haliaeetus leucocephalus	bald eagle	G5	S2	160
bird	Laterallus jamaicensis coturniculus	California black rail	G4T1	S1	37
bird	Melanerpes uropygialis	Gila woodpecker	G5	S1S2	15
bird	Piranga rubra	summer tanager	G5	S2	13
bird	Plegadis chihi	white-faced ibis	G5	S1	16
bird	Polioptila californica californica	coastal California gnatcatcher	G3T2	S2	81
bird	Rallus longirostris levipes	light-footed clapper rail	G5T1T2	S1	10
bird	Rallus longirostris obsoletus	California clapper rail	G5T1	S1	21
bird	Rallus longirostris yumanensis	Yuma clapper rail	G5T3	S1	20
bird	Riparia riparia	bank swallow	G5	S2S3	73

bird	Sternula antillarum browni	California least tern	G4T2T3Q	S2S3	21
bird	Strix nebulosa	great gray owl	G5	S1	31
bird	Vireo bellii pusillus	least Bell's vireo	G5T2	S2	90
invertebrate	Ancotrema voyanum	hooded lancetooth	G1G2	S1S2	12
invertebrate	Desmocerus californicus dimorphus	valley elderberry longhorn beetle	G3T2	S2	105
invertebrate	Euphilotes enoptes smithi	Smith's blue butterfly	G5T1T2	S1S2	10
invertebrate	Euphydryas editha bayensis	Bay checkerspot butterfly	G5T1	S1	12
invertebrate	Euphydryas editha quino	quino checkerspot butterfly	G5T1	S1	21
invertebrate	Helminthoglypta talmadgei	Trinity shoulderband	G1G3	S1S3	11
invertebrate	Lanx patelloides	kneecap lanx	G2	S2	12
mammal	Ammospermophilus nelsoni	Nelson's antelope squirrel	G2	S2	42
mammal	Aplodontia rufa californica	Sierra Nevada mountain beaver	G5T3T4	S2S3	11
mammal	Chaetodipus californicus femoralis	Dulzura pocket mouse	G5T3	S2?	28
mammal	Chaetodipus fallax fallax	northwestern San Diego pocket mouse	G5T3	S2S3	41
mammal	Corynorhinus townsendii	Townsend's big-eared bat	G4	S2S3	122
mammal	Dipodomys ingens	giant kangaroo rat	G2	S2	35
mammal	Dipodomys nitratoides brevinasus	short-nosed kangaroo rat	G3T1T2	S1S2	17
mammal	Dipodomys nitratoides nitratoides	Tipton kangaroo rat	G3T1	S1	29
mammal	Dipodomys stephensi	Stephens' kangaroo rat	G2	S2	37
mammal	Euderma maculatum	spotted bat	G4	S2S3	53
mammal	Gulo gulo	California wolverine	G4	S2	86
mammal	Macrotus californicus	California leaf-nosed bat	G4	S2S3	22
mammal	Martes americana humboldtensis	Humboldt marten	G5T2T3	S2S3	20
mammal	Martes pennanti (pacifica) DPS	Pacific fisher	G5	S2S3	170
mammal	Myotis ciliolabrum	western small-footed myotis	G5	S2S3	31
mammal	Nyctinomops femorosaccus	pocketed free-tailed bat	G4	S2S3	31
mammal	Nyctinomops macrotis	big free-tailed bat	G5	S2	18
mammal	Ochotona princeps muiri	Yosemite pika	G5T2T4	S2S4	13
mammal	Onychomys torridus tularensis	Tulare grasshopper mouse	G5T1T2	S1S2	14
mammal	Perognathus inornatus inornatus	San Joaquin pocket mouse	G4T2T3	S2S3	51
mammal	Perognathus longimembris brevinasus	Los Angeles pocket mouse	G5T1T2	S1S2	18
mammal	Reithrodontomys raviventris	salt-marsh harvest mouse	G1G2	S1S2	18
mammal	Spermophilus mohavensis	Mohave ground squirrel	G2G3	S2S3	102
mammal	Vulpes macrotis mutica	San Joaquin kit fox	G4T2T3	S2S3	217
mammal	Vulpes vulpes necator	Sierra Nevada red fox	G5T3	S1	47
plant	Didymodon norrisii	Norris' beard moss	G2G3	S2.2	12
plant	Meesia uliginosa	broad-nerved hump moss	G4	S2.2	12
plant	Mielichhoferia elongata	elongate copper moss	G4?	S2.2	12
plant	Abronia umbellata ssp. breviflora	pink sand-verbena	G4G5T2	S2.1	12
plant	Abronia villosa var. aurita	chaparral sand-verbena	G5T3T4	S2.1	17
plant	Acanthomintha ilicifolia	San Diego thorn-mint	G1	S1.1	16
plant	Achnatherum aridum	Mormon needle grass	G5	S2?	15
plant	Aliciella ripleyi	Ripley's aliciella	G3	S1.3	11
plant	Ambrosia pumila	dwarf burr ambrosia	G1	S1.1	11
plant	Amsinckia lunaris	bent-flowered fiddleneck	G2	S2.2	18
plant	Anisocarpus scabridus	scabrid alpine tarplant	G2G3	S2S3	11
plant	Arabis bodiensis	Bodie Hills rock-cress	G2	S1.2	10
plant	Arabis shockleyi	Shockley's rock-cress	G3	S2.2	11
plant	Arctomecon merriamii	white bear poppy	G3	S2.2	17
plant	Arctostaphylos canescens ssp. sonomensis	Sonoma canescent manzanita	G3G4T2	S2.1	13

plant	Arnica fulgens	hillside arnica	G5	S2.2	15
plant	Astragalus agnicidus	Humboldt County milk-vetch	G2	S2.1	12
plant	Astragalus oocarpus	San Diego milk-vetch	G2	S2.2	14
plant	Astragalus rattanii var. jepsonianus	Jepson's milk-vetch	G4T2	S2.2	14
plant	Astragalus tener var. tener	alkali milk-vetch	G1T1	S1.1	16
plant	Atriplex cordulata	heartscale	G2?	S2.2?	27
plant	Atriplex depressa	brittlescale	G2Q	S2.2	21
plant	Atriplex erecticaulis	Earlimart orache	G2	S2.2	12
plant	Atriplex joaquiniana	San Joaquin spearscale	G2	S2.1	29
plant	Atriplex minuscula	lesser saltscale	G1	S1.1	12
plant	Atriplex vallicola	Lost Hills crownscale	G1	S1.1	20
plant	Balsamorhiza macrolepis var. macrolepis	big-scale balsamroot	G3G4T2	S2.2	11
plant	Bloomeria clevelandii	San Diego goldenstar	G2	S2.2	15
plant	Boschniakia hookeri	small groundcone	G5	S1S2	11
plant	Botrychium ascendens	upswept moonwort	G2G3	S1.3?	11
plant	Botrychium crenulatum	scalloped moonwort	G3	S2.2	26
plant	Botrychium minganense	mingan moonwort	G4	S1.2	16
plant	Botrychium montanum	western goblin	G3	S1.1	14
plant	Bouteloua trifida	three-awned grama	G4G5	S2?	12
plant	Brodiaea filifolia	thread-leaved brodiaea	G2	S2.1	18
plant	Calliandra eriophylla	pink fairy-duster	G5	S2.3	10
plant	Calochortus clavatus var. gracilis	slender mariposa-lily	G4T1	S1.1?	10
plant	Calochortus palmeri var. palmeri	Palmer's mariposa-lily	G2T2	S2.1	11
plant	Calochortus striatus	alkali mariposa-lily	G2	S2.2	23
plant	Calochortus weedii var. intermedius	intermediate mariposa-lily	G3G4T2	S2.2	14
plant	Calochortus weedii var. vestus	late-flowered mariposa-lily	G3G4T2	S2.2	12
plant	Calycadenia hooveri	Hoover's calycadenia	G2	S2.2	11
plant	Calycadenia micrantha	small-flowered calycadenia	G2G3	S2S3.2	11
plant	Calycadenia villosa	dwarf calycadenia	G2	S2.1	13
plant	Campanula exigua	chaparral harebell	G2	S2.2	13
plant	Carex sheldonii	Sheldon's sedge	G4	S2.2	13
plant	Carex vulpinoidea	brown fox sedge	G5	S2.2	12
plant	Carlquistia muirii	Muir's tarplant	G2	S2.3	11
plant	Castela emoryi	Emory's crucifixion-thorn	G3	S2.2	16
plant	Castilleja affinis ssp. litoralis	Oregon coast paintbrush	G4G5T4	S2.2	11
plant	Castilleja campestris ssp. succulenta	succulent owl's-clover	G4?T2	S2.2	19
plant	Castilleja densiflora ssp. obispoensis	San Luis Obispo owl's-clover	G5T2	S2.2	10
plant	Castilleja rubicundula ssp. rubicundula	pink creamsacs	G5T2	S2.2	11
plant	Caulanthus coulteri var. lemmonii	Lemmon's jewelflower	G4T2	S2.2	15
plant	Ceanothus confusus	Rincon Ridge ceanothus	G2	S2.2	11
plant	Centromadia parryi ssp. australis	southern tarplant	G4T2	S2.1	16
plant	Centromadia parryi ssp. parryi	pappose tarplant	G4T2	S2.2	12
plant	Centromadia pungens ssp. laevis	smooth tarplant	G3G4T2	S2.1	19
plant	Chamaesyce hooveri	Hoover's spurge	G2	S2.1	10
plant	Chlorogalum grandiflorum	Red Hills soaproot	G2	S2.2	17
plant	Chorizanthe parryi var. parryi	Parry's spineflower	G2T2	S2.1	14
plant	Chorizanthe polygonoides var. longispina	long-spined spineflower	G5T3	S2.2	24
plant	Chorizanthe rectispina	straight-awned spineflower	G1	S1.2	10
plant	Cladium californicum	California saw-grass	G4	S2.2	10
plant	Clarkia biloba ssp. brandegeeae	Brandegee's clarkia	G4G5T2	S2.2	19
plant	Clarkia borealis ssp. borealis	northern clarkia	G3T2	S2.3	10

plant	Clarkia gracilis ssp. albicaulis	white-stemmed clarkia	G5T2	S2.2?	10
plant	Clarkia mosquinii	Mosquin's clarkia	G1	S1.1	10
plant	Clarkia xantiana ssp. parviflora	Kern Canyon clarkia	G4T1	S1.2	13
plant	Comarostaphylis diversifolia ssp. diversifolia	summer holly	G3T2	S2.2	15
plant	Coptis laciniata	Oregon goldthread	G4G5	S2.2	17
plant	Cordylanthus mollis ssp. hispidus	hispid bird's-beak	G2T2	S2.1	11
plant	Cryptantha crinita	silky cryptantha	G1	S1.1	11
plant	Cymopterus gilmanii	Gilman's cymopterus	G3?	S2.2	14
plant	Dedeckera eurekensis	july gold	G2	S2.2	10
plant	Deinandra mohavensis	Mojave tarplant	G2	S2.3	11
plant	Delphinium recurvatum	recurved larkspur	G2	S2.2	31
plant	Delphinium umbraculorum	umbrella larkspur	G2G3	S2S3.3	21
plant	Dimeresia howellii	doublet	G4?	S2.3	17
plant	Dirca occidentalis	western leatherwood	G2G3	S2S3	14
plant	Drosera anglica	English sundew	G5	S2S3	10
plant	Dudleya multicaulis	many-stemmed dudleya	G2	S2.1	23
plant	Dudleya variegata	variegated dudleya	G2	S2.2	12
plant	Epilobium oreganum	Oregon fireweed	G2	S2.2	18
plant	Epilobium siskiyouense	Siskiyou fireweed	G3	S2.2	16
plant	Eriogonum prociduum	prostrate buckwheat	G3	S2.2	12
plant	Eriophyllum mohavense	Barstow woolly sunflower	G2	S2.2	15
plant	Eryngium aristulatum var. parishii	San Diego button-celery	G5T2	S2.1	14
plant	Eryngium spinosepalum	spiny-sepaled button-celery	G2	S2.2	16
plant	Erythronium revolutum	coast fawn lily	G4	S2.2	22
plant	Eschscholzia lemmonii ssp. kernensis	Tejon poppy	G5T1	S1.1?	10
plant	Fritillaria liliacea	fragrant fritillary	G2	S2.2	20
plant	Fritillaria pluriflora	adobe-lily	G2	S2.2	18
plant	Hesperolinon adenophyllum	glandular western flax	G2	S2.3	12
plant	Hesperolinon sp. nov. "serpentinum"	Napa western flax	G2	S2.1	12
plant	Hibiscus lasiocarpus	woolly rose-mallow	G4	S2.2	30
plant	Horkelia cuneata ssp. puberula	mesa horkelia	G4T2	S2.1	13
plant	Horkelia cuneata ssp. sericea	Kellogg's horkelia	G4T1	S1.1	10
plant	Horkelia truncata	Ramona horkelia	G3	S2.3	13
plant	Imperata brevifolia	California satintail	G2	S2.1	16
plant	Ivesia sericoleuca	Plumas ivesia	G2	S2.2	17
plant	Juncus leiospermus var. leiospermus	Red Bluff dwarf rush	G2T2	S2.2	19
plant	Lasthenia conjugens	Contra Costa goldfields	G1	S1.1	14
plant	Lasthenia glabrata ssp. coulteri	Coulter's goldfields	G4T3	S2.1	15
plant	Lathyrus jepsonii var. jepsonii	Delta tule pea	G5T2	S2.2	19
plant	Layia heterotricha	pale-yellow layia	G2G3	S2S3.1	32
plant	Layia septentrionalis	Colusa layia	G2	S2.2	17
plant	Legenere limosa	legenere	G2	S2.2	25
plant	Lepidium virginicum var. robinsonii	Robinson's pepper-grass	G5T2?	S2.2	11
plant	Lewisia cotyledon var. heckneri	Heckner's lewisia	G4T2	S2.2	13
plant	Lewisia disepala	Yosemite lewisia	G2	S2.2	11
plant	Lilium maritimum	coast lily	G2	S2.1	10
plant	Lilium parryi	lemon lily	G3	S2.1	19
plant	Limosella subulata	Delta mudwort	G4?Q	S2.1	12
plant	Loeflingia squarrosa var. artemisiarum	sagebrush loeflingia	G5T2T3	S2.2	15
plant	Lomatium foeniculaceum var. macdougalii	Macdougal's lomatium	G5T4T5	S2.2	10
plant	Lupinus sericatus	Cobb Mountain lupine	G2	S2.2	10

plant	Madia radiata	showy golden madia	G2	S2.1	13
plant	Malacothamnus davidsonii	Davidson's bush-mallow	G1	S1.1	11
plant	Malacothamnus hallii	Hall's bush-mallow	G1Q	S1.2	12
plant	Mimulus evanescens	ephemeral monkeyflower	G2	S1.2	10
plant	Mimulus pictus	calico monkeyflower	G2	S2.2	11
plant	Mimulus pulchellus	yellow-lip pansy monkeyflower	G2G3	S2S3.2	12
plant	Monardella hypoleuca ssp. lanata	felt-leaved monardella	G4T2	S2.2	13
plant	Monardella villosa ssp. globosa	robust monardella	G5T2	S2.2	15
plant	Monotropa uniflora	ghost-pipe	G5	S2S3	10
plant	Myosurus minimus ssp. apus	little mousetail	G5T2Q	S2.2	14
plant	Navarretia fossalis	Moran's navarretia	G2	S2.1	15
plant	Navarretia leucocephala ssp. bakeri	Baker's navarretia	G4T2	S2.1	12
plant	Navarretia nigelliformis ssp. radians	shining navarretia	G4T2T3	S2S3.2	16
plant	Nolina cismontana	Peninsular nolina	G1	S1.1	12
plant	Opuntia basilaris var. brachyclada	short-joint beavertail	G5T1	S1.2	14
plant	Opuntia basilaris var. treleasei	Bakersfield cactus	G5T2	S2.1	12
plant	Orcuttia californica	California Orcutt grass	G2	S2.1	11
plant	Orcuttia inaequalis	San Joaquin Valley orcutt grass	G2	S2.1	15
plant	Orcuttia pilosa	hairy orcutt grass	G2	S2.1	12
plant	Packera layneae	Layne's ragwort	G2	S2.1	12
plant	Paronychia ahartii	Ahart's paronychia	G2	S2.1	17
plant	Penstemon calcareus	limestone beardtongue	G2	S2.3	14
plant	Penstemon sudans	Susanville beardtongue	G2G3	S2.3	16
plant	Phacelia greenei	Scott Valley phacelia	G2	S2.2	10
plant	Phacelia leonis	Siskiyou phacelia	G2	S2.2	10
plant	Phlox muscoides	squarestem phlox	G5?	S2S3	10
plant	Pseudobahia peirsonii	San Joaquin adobe sunburst	G2	S2.1	16
plant	Raillardella pringlei	showy raillardella	G2	S2.2	10
plant	Rhynchospora capitellata	brownish beaked-rush	G5	S2S3	13
plant	Scrophularia atrata	black-flowered figwort	G2	S2.2	10
plant	Senecio aphanactis	chaparral ragwort	G3?	S1.2	10
plant	Senna covesii	Coves' cassia	G5?	S2.2	11
plant	Streptanthus albidus ssp. peramoenus	most beautiful jewel-flower	G2T2	S2.2	17
plant	Symphyotrichum greatae	Greata's aster	G2	S2.3	12
plant	Thermopsis robusta	robust false lupine	G2Q	S2.2	18
plant	Tuctoria greenei	Greene's tuctoria	G2	S2.2	13
plant	Viola pinetorum ssp. grisea	grey-leaved violet	G4G5T1	S1.3	10
reptile	Aspidoscelis hyperythra	orange-throated whiptail	G5	S2	69
reptile	Aspidoscelis tigris stejnegeri	coastal western whiptail	G5T3T4	S2S3	53
reptile	Crotalus ruber ruber	northern red-diamond rattlesnake	G4T3T4	S2?	44
reptile	Eumeces skiltonianus interparietalis	Coronado skink	G5T2T3Q	S1S2	19
reptile	Gambelia sila	blunt-nosed leopard lizard	G1	S1	85
reptile	Gopherus agassizii	desert tortoise	G4	S2	42
reptile	Masticophis flagellum ruddocki	San Joaquin whipsnake	G5T2T3	S2?	45
reptile	Masticophis lateralis euryxanthus	Alameda whipsnake	G4T2	S2	16
reptile	Phrynosoma mcallii	flat-tailed horned lizard	G3	S2	28
reptile	Salvadora hexalepis virgultea	coast patch-nosed snake	G5T3	S2S3	15
reptile	Thamnophis gigas	giant garter snake	G2G3	S2S3	55
reptile	Thamnophis hammondii	two-striped garter snake	G3	S2	67
reptile	Uma inornata	Coachella Valley fringe-toed lizard	G1Q	S1	12