1. Introduction

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Greenhouse gases are accumulating in the atmosphere as a result of burning fossil fuels and other human activities such as deforestation (Houghton et al., 2001). Without abatement, future emissions are expected to increase concentrations in the atmosphere substantially. These greenhouse gases essentially trap heat in the atmosphere. Climate scientists have concluded that recent increases in global temperatures are largely the result of increased greenhouse gas concentrations and that the continued increase in these concentrations will cause future climate warming (Houghton et al., 2001). Even if aggressive steps are taken to control the emissions of greenhouse gases, there is every reason to believe that the climate will continue to change, although the precise increases in temperature and changes in precipitation are uncertain. These changes could have substantial impacts on the Earth’s coastal resources, water supplies, agricultural output, biodiversity, and other sectors. Every region around the world consequently needs to plan how they will adapt to climate change. This includes examining how society and nature may be affected by changes in climate and whether it is prudent to take actions now and in the future to avoid harmful impacts and take advantage of beneficial impacts.

This book is a comprehensive and integrated study of a single region, California. The state is important not just because it is home to 35 million people and has a large and vibrant economy, but because its development was the result of major engineering of its natural resources. In particular, the state has one of the most sophisticated water collection and distribution systems in the world. Table 1.1 gives a brief overview of California.

The project was designed to help California natural resource managers and other policy makers better understand the potential effects of climate change on the state. Indeed, the ultimate goal of the book is to quantify the impacts of climate change for California and make available information that natural resource policy makers can use to develop adaptive policies.

The book focuses on two key questions: To what extent would a change in climate affect California? And, what is the potential for the state to adapt to climate change?
Table 1.1  California statistics

Topography  423,970 km² (163,969 square miles).
Third largest state in US.
Elevations: from 86 m (282 ft) below sea level (Death Valley) to 4414 m (14,494 ft) atop Mt. Whitney. Greatest complexity of topography among US states.
Mountain ranges: Klamath and Cascade in the north; Sierra Nevada along most of the eastern border; Coastal range close to the coast.
Central Valley is between Sierra and Coastal Range.
Major rivers: Sacramento, San Joaquin.

Climate  Varies widely.
Precipitation: mainly in winter, heavy in northwestern portion; very dry inland and south of Los Angeles.
Temperature: mild in maritime region and in winter, except in mountainous areas; very hot inland.

Ecosystems  Great diversity due to variability in elevation, topography, soils, climate:
alpine tundra, temperate rainforest, intertidal wetlands, grasslands, arid deserts.
More than 5000 native plants, 1000 vertebrates.\(^a\)
48% of species endemic.\(^b\)
Forests cover 40% of land area.

Population  35.5 million (2003).
Largest cities: Los Angeles, San Diego, San Jose, San Francisco, Long Beach, Fresno, Sacramento, Oakland.
One-half of state’s population in southern California.\(^c\)

Economy  Largest in US; GSP of $1.4 trillion (2003).\(^d\)
Main economy sectors: agriculture, mining, entertainment, aerospace, government, education, tourism, high tech.

Agriculture  Largest value producer in US.
87,500 farms, average size 151 ha (374 acres).
4% of total farms in US, 13% of national farm income.
200 commercial crops, annual export value in late 1990s $6.6 billion (2% of total GSP).

Forestry  Timber harvest 3.8 million m³ (1.6 billion board feet) in early 2000s, value of $570 million.
Production of mainly softwoods, in coastal ranges and Sierra Nevada.

Notes:
This research builds on a number of previous studies of climate change impacts on California, including Smith and Tirpak (1989), Knox and Scheuring (1991), Field et al. (1999), Wilkinson (2002), Barnett et al. (2004), and Hayoe et al. (2004). These previous studies addressed impacts of climate change on such resources as water supplies, agriculture, coastal resources, air quality, and natural resources.

This study makes several important improvements over earlier regional and national assessments of climate change impacts. First, it develops two relatively detailed projections about population growth, land use, economic growth, and technological improvements in California over the twenty-first century. The scenarios are discussed in more detail below.

Second, the study integrates the results of natural science and economics. It does not estimate just physical changes such as change in runoff or snowpack (for example Hayhoe et al., 2004) but also the consequences of those changes and the potential ability of societal systems to adapt to them. For example, the study develops a complex, integrated, water–agriculture economic model to estimate changes in water supply, demand, and distribution. This model predicts outcomes in both the water sector and the agricultural sector. It is by far the most detailed and integrated analysis of water resources and irrigated agriculture yet conducted.

Third, the study includes a detailed analysis of how California’s terrestrial ecosystems and biodiversity may be affected by climate change. It includes a spatially detailed analysis of how climate change might change valuable habitats. It then combines that analysis with a highly detailed set of projections on future land development to examine the combined impacts of climate change and development on the state’s biodiversity.

The structure of the study is displayed in Figure 1.1. The first step was creation of baseline scenarios of socio-economic conditions (population, income, and land use); these baseline socio-economic scenarios are discussed in Chapter 2. The baselines are dynamic projections of growth in the region. Although it is likely that California will continue to grow, it is not clear how quickly it will do so. To capture some of the uncertainty about future population and economic growth, the study examines two dynamic pathways, a low-growth and a high-growth scenario. In the low-growth scenario, 67 million people are living in California by 2100 and in the high-growth scenario there are 92 million people by 2100. Both socio-economic scenarios assume that per capita income will grow, although at different rates.

Chapter 3 examines how land use in the state could change over time in response to the population growth. The study addresses the extent to which infill development can provide sufficient housing and the extent to which new development may be needed. Further, the land use modeling predicts what counties are likely to see the highest growth in population. These
assumptions turn out to be quite important for understanding what could happen to natural open space (Chapter 6) and what could happen to agricultural land (Chapter 11) under the combined effects of population growth and climate change.

The second step was to create a set of climate change scenarios that reflect the broad potential array of future changes in climate (Chapter 4). The Intergovernmental Panel on Climate Change (IPCC) has determined that the range of possible temperature changes for the world by 2100 lies between 1.4°C and 5.8°C (Houghton et al., 2001). While there is little doubt that temperatures in California will increase over the century, there is uncertainty about whether annual precipitation will increase or decrease. To be useful for policy makers, it is important that climate change scenarios reflect this broad range of potential changes in climate for California (or any region being studied). Some studies have used only climate change scenarios with substantial increases in precipitation (for example Wilkinson, 2002), while others have relied mainly on scenarios that estimate substantial decreases in precipitation (for example Hayhoe et al., 2004). Relying on limited scenarios can be misleading and give the wrong impression that a single scenario is the only possible outcome for California over the coming century. We selected several temperature and precipitation scenarios to capture a broad range of possible outcomes. All the scenarios used in this study include higher temperatures, but some include increased precipitation, others include little change in precipitation, and others include decreased precipitation. By including both warmer and wetter, and warmer and drier scenarios, the study reflects the uncertainty about potential changes in California’s climate and presents a broader range of potential impacts than would come from a more limited set of climate change scenarios.

The scenarios were then used in individual studies displayed in the boxes in the second and third rows of Figure 1.1 to assess potential impacts of climate change on various sectors of the economy and the natural environment. The results of some of these studies were used as inputs into other related studies.

Chapter 5 estimates how the distribution of major terrestrial ecosystems could be affected by climate change. It also estimates how productivity of the ecosystems could change and how fire frequency could be affected by climate change. The results of Chapter 5 on terrestrial vegetation changes were used in both Chapter 6 on biodiversity and Chapter 7 on forestry. Chapter 6 combines the projections of land use change with the estimates of changes in terrestrial ecosystem location. The model provides one of the first estimates of dynamic ecosystem adjustments in the literature. This analysis is used to examine how biodiversity may change and how one critical habitat, coastal sage scrub, could be affected by development and climate change. Chapter 7 examines how changes in the productivity and location of species could affect the productivity of the forestry sector in California. The chapter combines estimation of how climate change might affect softwood growth in the state with projections of global forestry production changes that might affect timber prices.

Chapters 8 through 11 present the most detailed and integrated assessment conducted of how climate change could affect California’s water supplies and agricultural economy. Chapter 8 estimates changes in runoff in six representative and important river basins in California. Chapter 9 estimates how crop yields could be affected by continued but slow improvements in technology as well as changes in climate. The latter considers the direct effects of changes in temperature and precipitation and the carbon dioxide fertilization effect. The study estimates changes in crop yields and in demand for irrigation.

The results of Chapter 8 on runoff and Chapter 9 on crop water were used in both Chapter 10 on water resources and Chapter 11 on agriculture. Chapters 10 and 11 use general equilibrium modeling to examine climate impacts on the water and agricultural systems, respectively. These two chapters are tightly linked because the vast majority of the state’s water supplies are used by irrigated agriculture. The water resources chapter uses a complex model where changes in snowpack, surface water runoff, and groundwater supplies are inputs. The water model estimates changes in water demand from population growth and warming. The model then calculates where water supplies would be most efficiently allocated. The agriculture model
starts with changes in land use, water supplies, crop yields, and irrigation demand from climate change. The model then calculates how many acres farmers will plant and irrigate, where they would be planted (and not planted), and which crops would be chosen. The result of all these adaptations leads to a final welfare estimate of agricultural impacts.

The remaining chapters address two other key sectors, energy and coastal resources. Chapter 12 examines the potential effect of climate change on energy demand for space cooling and heating. Chapter 13 examines what might happen along California’s developed coast if the sea level rises. It estimates whether developed coastlines would be protected from sea level rise or be inundated.

The book concludes with Chapter 14 which summarizes the overall results. Market impacts are summed and compared. Non-market impacts are discussed as quantitatively as possible. The strengths and weaknesses of the overall methods are reviewed and future research initiatives are proposed. The conclusion also discusses the many policy implications of the results. How important are climate change impacts to California? What policy changes are needed to help the state adapt to future scenarios? How soon should planners prepare for climate change?

This study can be a model for how other regional assessments can be conducted. In particular, the use of multiple scenarios of socio-economic development, a wide range of climate change scenarios, and detailed and integrated analysis of impacts and adaptation potential are important for better understanding the potential consequences of climate change.

NOTE

1. Smith and Tirpak (1989) had a chapter on California, whereas the other studies focused exclusively on California.

REFERENCES


