Chapter 3.7
Climate Change: Threats and Opportunities

America's forests offset a significant portion of the nation's annual carbon emissions. Additional climate change mitigation benefits could be achieved through partnerships and management measures. These measures include supporting the development of markets for carbon offsets, utilizing woody biomass for energy, wood product substitution, and promoting tree growth in urban areas. Assessments should identify opportunities for promoting carbon emissions offsets through forestry.

The important benefits that forests provide such as, biodiversity, wildlife habitat, and water storage and flows are affected by climate change. Forest range, type and composition are projected to change significantly– with corresponding changes in wildlife habitat, biodiversity, water flows, and fire regimes. Assessments should consider how climate change will affect important public benefits from forests. Resource strategies should attempt to maintain and enhance resilient and connected forest ecosystems that will continue to provide public benefits in a changing climate (excerpted from the U.S. Forest Service State and Private Forestry Farm Bill Requirement and Redesign Strategies).

KEY FINDINGS

This chapter consists of an analysis of environmental trends in primary climate variables, followed by an assessment of threats to forest carbon under future climate scenarios, and concludes with an evaluation of the adaptive response of forest vegetation under future climate scenarios. Results from each analysis are summarized below.

Evaluation of Environmental Trends

A climate threat index was developed using data from downscaled global climate models (GCMs), which allowed for a comparison of changes in climate variables by Baily's U.S. Department of Agriculture ecological unit.

- The results show an expected increase in temperature among all ecological units, but the magnitude of the increase varies with ecological units. For all ecological units, average annual temperatures are expected to increase within the range of 0.8 degrees Celsius (1.4 °F) in 2039 to 2.7 degrees Celsius (4.9 °F) in 2099.
- Maximum daily temperatures during summer months showed the greatest increase in interior ecological sections including: Northwestern Basin and Range, Modoc Plateau, Mojave/Sonoran/Colorado deserts, Sierra and the Sierra foothill ecological sections. Temperature changes alone are expected to result in declining snowpack, affecting water resources and related environmental services.
- A variable pattern of annual precipitation is expected; increasing through 2069, then followed by a large decrease by 2099.

Forest Carbon – Threats from Wildfire, Insects and Disease and Development

Aboveground forest carbon was estimated using data from the MC1 vegetation dynamics model to evaluate expected changes in forest carbon in 2020, 2050 and by 2100. The analysis identified locations where high value forest carbon assets coincide with high risks, such as wildfire, insects, disease and development that threaten the sustainability of carbon sequestration.

- Carbon stocks were found to be mostly stable through 2050 and then declining substantially through 2100.
- Below-ground carbon pools showed less variation than aboveground carbon pools.
- The expected loss of carbon sequestration from wildfire, insects and disease was much more extensive than from development.
- Threats to the loss of terrestrial carbon (forest and range) from development were greatest in the San Francisco Bay Area, and the South Coast and Sacramento Valley bioregions. The current amount of medium and high priority landscapes are two to three percent in 2010 expanding to 10 to 14 percent by 2100.

Vegetation Response – BioMove

The response of forest species to climate change was also evaluated. Through collaboration with researchers at UC Santa Barbara, a climate change model (BioMove) was used to predict future shifts in range of tree species. A species distribution model was generated for a set of indicator species found in Table 3.7.6.

- The results show a mixed response among tree species, with some species showing an expansion in range and some species contracting in range by 2080.
- The two climate models used to estimate future conditions were reasonably consistent in predicting the shift in a species range. For several of the indicator species both GCMs predicted gains or losses in range that were within 10 percent of each other. Although for one species, giant sequoia (*Sequoiadendron giganteum*), the estimated extent of gain in species range varied by 58 percent between the two climate models.
- Many tree species showed a shift toward higher elevations and towards northern latitudes.

FORESTS AND CLIMATE CHANGE

Environmental Changes: Observed and Expected Trends

While climate model results differ, there are likely to be significant changes in the composition of forests throughout the state under all scenarios and models. In some cases, environmental effects from climate change have already been observed in California forests and rangelands (Cayan et al., 2006). This includes shifts in species ranges, changes in frequency of disturbance from wildfires and pests, and effects on forest productivity. Following is an overview of many of the observed and expected changes in climate.

Climate Change and Environmental Effects on Forests and Rangeland

Climate can greatly influence the dynamics of forest and rangeland ecosystems. Climate influences the type, mix and productivity of species. Future climate change scenarios predict increases in temperature, increases in atmospheric CO2 concentrations and changes in the amount and distribution of precipitation (Cayan et al., 2006). Altering these fundamental drivers of climate can result in changes in tree growth, changes in the range and distribution of species, and alteration to disturbance regimes (e.g., wildfires, outbreaks of pests, invasive species).

Given the long lifespan of trees in a forest stand, from decades to hundreds of years, the effects of climate change on disturbance regimes may become apparent prior to noticeable changes in forests and rangelands. These include changes in the timing, frequency and magnitude of wildfires, pest infestations and other agents of disturbance (Dale et al., 2001). While disturbances occur regularly in nature, large changes in the patterns of disturbance could make forests less resilient. Vegetation types with restricted ranges may be more vulnerable than others, as well as areas that are already under stress from land use (e.g., expansion of wildland urban interface) and management (Foster, 2003).

The influence that climate has on disturbance regimes may already be affecting forests and rangelands. In California, extended drought and earlier snowmelt are leading to longer and drier summers with more pronounced fire activity. Relatively small changes in temperature and precipitation can affect reforestation success, growth and forest productivity. Table 3.7.1 summarizes climate change effects that have already been detected and those that are expected under future climate scenarios.

Temperature

Temperature in California and the western states has been increasing (Cayan et al., 2006). The 1990s was one of the warmest decades on record since 1861. Over the last 100 years, the nine warmest years have occurred in the last 14 years (DWR, 2008). Climate models forecast increased temperatures that range from 1.7 degrees Celsius to 5.8 degrees Celsius between 2000 and 2100 depending on the model and the assumed emissions scenario (Cayan et al., 2006). This single factor can have broad reaching implications for the forest sector. In areas where water availability is not limiting, forests may expand under warming temperatures, while drier areas may

Table 3.7.1. Climate change impacts in the forest sector

Factor	Description
Hydrologic	Changes in temperature, precipitation, and hydrologic processes (e.g., decreased snowpack, earlier spring runoff, lower summer baseflow).
Fire	Changes in the extent and frequency of disturbances from wildfires, pests, and disease outbreaks.
Biologic	Conditions may favor the spread of invasive species.
Biologic	Tree species expected to move northward or to higher altitudes.
Biologic	Changes in reforestation and regeneration success.
Biologic	Changes in forest productivity affecting growth and carbon storage. The effect of additional CO2 on forest productivity is uncertain.
Economic	Economic impacts from increased fire damage and fire suppression costs.

Data Source: PEW Center on Global Climate Change, 2008 see regeneration failures of some species and a loss of productivity. Temperature increases are expected to be more pronounced during summer months, but also show a trend towards warmer winters. Some studies have suggested that temperature increases will vary across California, with higher increases in the Sierra Nevada Mountains (Snyder et al., 2002).

Precipitation

Precipitation variability has been a natural part of California's historic climate. Studies of tree ring data suggest that the last 200 years have been relatively wet and that the longer historic record has been composed of periods of prolonged drought (Meko et al., 2001).

Although GCMs are fairly consistent in their predictions of increasing temperature, there is less agreement among models forecasting precipitation patterns. While models show variation in wetter or drier trends, the seasonal distribution of rainfall is still typical of Mediterranean climate, with most precipitation occurring during the winter months. In general, the climate models show little or no change in annual precipitation, but they do show substantial inter-annual and decadal fluctuations in precipitation (Cayan et al., 2006).

Hydrology

Recent winters have been warmer and snow melt has begun sooner. Studies have documented declines in snow water equivalent from 1925 to 2000 that correlate with increases in temperature (Mote, 2005). The timing of snowmelt and spring runoff can lead to longer dry periods in the summer months and reduced moisture availability for forest plants. With less snow, the peak in spring runoff occurs sooner (Peterson et al., 2008). The decline in snowpack is expected to reduce current snowpack by up to 90 percent by 2100 (Anderson, 2008; Mote, 2005).

Climate models forecast this trend to continue. Coupled with warmer temperatures, climate models predict decreases in snow accumulation and a greater percentage of precipitation from rainfall (Knowles et al., 2006). This also leads towards an expectation of earlier snowmelt. Climate model simulations suggest that snowpack losses are likely to occur more quickly in milder climates and lower elevations. Slower losses are expected at higher elevations and particularly in the mountainous regions in the southern Sierra (Mote, 2005; Hayhoe et al., 2004). This has been shown through predictive models to affect the timing of river flows in the Sierra that are supported by snowmelt (Dettinger et al., 2004). Research has speculated that a change resulting in earlier and shorter spring runoff from snowmelt will likely affect water supply (Roos, 2003). Chapter 2.1 contains additional information on climate change impacts to water resources.

Wildfire

The size, severity, duration and frequency of fires are greatly influenced by climate. Although fires are a natural part of the California landscape, the fire season in California and elsewhere seems to be starting sooner and lasting longer, with climate change being suspected as a key mechanism in this trend (Flannigan et al., 2000; Westerling et al., 2006). The rolling five year average for acres burned by wildfires on all jurisdictions increased in the past two decades from 250,000 to 350,000 acres (1987–1996) to 400,000 to 600,000 acres (1997–2006) (2006, California Wildfire Activity Statistics). In addition, the three largest fire years since 1950 have occurred this decade, with both 2007 and 2008 exceeding the previous five-year average.

An increase in wildfires has been attributed in part to warmer spring and summer temperatures, reduced snowpack and earlier spring snowmelt, as well as increased frequency of Santa Ana conditions (Mote, 2005; Westerling and Bryant, 2006; Bryant and Westerling, 2009). Warmer and drier conditions may also lead to increased moisture stress that can result in an earlier and thus longer fire season. An increase in wildfire frequency may mean an increase in greenhouse gas (GHG) emissions and a corresponding increase in the number of bad air days. Alternatively, a wetter climate scenario may reduce rate of spread

(Fried et al., 2006), but may increase fuels and thus increase wildfire hazard.

Wildfire risk will continue to be highly variable across the state. Research suggests that large fires and burned acreage will increase throughout the century (Westerling and Bryant, 2006; Lenihan et al., 2008), with some declines after mid-century due to vegetation type conversions. Recent research estimates that the wildfire area burned is expected to increase by at least 100 percent in the forests of Northern California (Westerling et al., 2009). This estimate was consistent for the three GCMs that were used in the analysis.

Impacts on Tree Species and Ecosystem Shifts

With warmer temperatures, tree species in California are likely to respond by migrating both northward and to higher altitudes (Shugart et al., 2003). As the rate of climate change increases some tree species may not be able to adapt to changed conditions. It is expected that species with currently restricted ranges will be most vulnerable, while species with broader climate tolerances may be able to adapt more easily. Alpine forests and related plant species are particularly vulnerable. With projected temperature increases, their habitat range is likely to be compressed with little room to expand. Forest adaptations from paleoclimate studies have documented the advancing and retreating tree line for sub-alpine conifers, as well as other species in the Sierra (Stine, 1996).

The simulated effect of climate on the distribution of vegetation types has been analyzed for several different climate change scenarios (Lenihan et al., 2006). Under all three scenarios, Alpine/Sub-alpine forest cover declined with increased growing season and warming temperatures. Conifer forests were displaced by mixed evergreen forest, and declines in the extent of woodlands and shrubland were due to encroachment by forest types and grassland.

Productivity Changes

Climate change effects on tree growth are uncertain, due largely to uncertainties about precipitation and water availability, and also by a limited understanding of the effects that increased CO2 could have on plant growth (Stugart, 2003). For example, Lenihan et al., (2006) showed increased woody biomass over the next century using a wetter climate scenario model, but showed biomass decreases when using the drier climate scenario model. In a related study, Battles et al., (2006) predicted reduced conifer tree growth of up to 18 percent in mature stands and up to 31 percent for pine plantations that would result under a warmer climate scenario. However, preliminary results in more recent studies have shown an increase in pine yield with corresponding increases in temperature (Battles et al., 2009). Recent studies in other areas of North America suggest a general trend of increased productivity in response to climate change, where ranges are stable and water is not limiting (McMahon et al., 2010).

Global Climate Models: Projected Trends

The future climatic conditions in California are uncertain and dependent on a complex set of social and biophysical systems. To account for this variability the Intergovernmental Panel on Climate Change (IPCC) developed a set of possible future emissions scenarios based on different assumptions about pathways for economic, demographic and technological change, which resulted in a broad range of emissions scenarios. The analysis presented in this chapter is based largely on a higher emissions scenario (A2) and in some cases contrasted with results from a lower emissions scenario (B1). See Cayan et al., (2006) for a review of GCMs and emissions.

Role of Forests in Adaptation and Mitigation

Forests that are managed sustainably can help mitigate or offset the emissions of CO2 and other GHGs. Mitigation generally refers to any activities that are aimed at reducing GHG emissions. In forestry this can include both actions that lead to additional carbon sequestration, as well as actions that reduce emissions associated with wildfires, land use conversions and other forms of disturbance. The California Department of Forestry and Fire Protection (CAL FIRE) has identified five strategies to mitigate against GHG emissions: reforestation, forestland conservation, fuels reduction, urban forestry, and forest management to improve carbon sequestration.

As described in the previous section, climate change itself can have detrimental effects on forests. With the increasing certainty found in recent climate change reports (IPCC, 2007; Cayan et al., 2006) it appears that even with reductions in GHG emissions, some level of climate change is likely and adaptation strategies will be needed to maintain productive forests and rangelands.

Adaptation

Adaptation to climate change is any activity that reduces the negative impacts of climate change or takes advantage of new opportunities that may be presented. Within the forest sector, adaptation is defined as actions that are undertaken to increase the capacity of forests, ecosystems and society to function productively and cope with impacts from climate change (Millar et al., 2007). This can include actions that are taken before impacts are observed (proactive) and after impacts have been felt (reactive) (Easterling et al., 2004). The goal of adaptation planning is to reduce the vulnerability of forests and rangelands to climate changes and to increase the resiliency of lands to climate change. Resiliency is defined as the ability of a system, managed or natural, to withstand negative impacts without losing its basic functions. This does not imply that adaptation prevents impacts from occurring, but rather promotes more resilient ecosystems.

Adaptation to climate change impacts will require making decisions with limited information and with uncertain outcomes. This underscores the need to make long-term investments in monitoring and research and to develop a robust set of management options. The 2009 California Climate Adaptation Strategy (CAS) report includes a number of approaches, including both near- and long-term actions, which will help California forests adapt to climate change. Forest sector strategies in the CAS report are focused on (http://www.climatechange.ca.gov):

- Incorporating climate information into policy and program planning
- Improving the institutional capacity to assess climate effects and forest vulnerabilities
- Management actions to address and minimize forest vulnerabilities
- Implementing a priority research agenda
- Continued emphasis on forest health monitoring

Analysis – Climate Threat Index (Projected Trends)

To better understand expected trends in key climate variables, an analysis of downscaled climate data from GCMs was conducted. Daily climate data was collected to assess expected changes in future conditions from 2010 to 2100. The data was provided by the California Energy Commission and was originally collected as part of the Climate Scenario's Project which was directed by the California Climate Change Center (Cayan et al., 2006; Cayan et al., 2008). The following climate variables were included in the analysis.

- Annual Temperature
- Summer Temperature Max (June, July, August, September)
- Winter Temperature Min (December, January, February)
- Annual Precipitation
- Snow Water Equivalent

A Climate Threat Index was developed using downscaled climate change data from the Geophysical Fluid Dynamics Laboratory (GFDL) global climate model for the B1 climate scenario (Hidalgo et al., 2008). This index was used to identify the deviation of future climate conditions from historic conditions for each climate variable. Data for each variable was summarized to estimate average conditions for the following time periods:

- Historic T1 (June–Sept.) 1970–1999
- Future T2 (June–Sept.) 2010–2039
- Future T3 (June–Sept.) 2040–2069
- Future T4 (June–Sept.) 2070–2099

The index was calculated for a regularly spaced grid of points across California. These points were then overlayed with a GIS layer representing ecological units for California (Figure 3.7.1). This stratification allowed for a comparison of climate trends among ecological units.

Results

Using the climate threat index, expected trends in temperature and precipitation was evaluated for future time periods when compared to historic conditions (1970–1999). For all ecological units average annual temperatures are expected to increase within the range of 0.8 degrees Celsius in 2039 to 2.41 degrees Celsius in 2099. Estimated increases are consistent with predictions for increased warming from other studies, but are lower in the magnitude of expected change (Cayan et al., 2008; Bonfils et al., 2008). The differences may be attributed to the averaging that was used to develop the climate threat index in this study. The temperature increases represent the difference from a baseline temperature (i.e., historic average 1970–1999) and an estimated average annual temperature for a future time step (i.e., average annual temperature 2070–2099). Seasonal differences were also evaluated in a similar manner. The climate threat index was calculated for a grid of points, with 12 kilometer spacing, covering California. A table of the results by ecological units is presented in Table 3.7.2. In addition to evaluating statewide trends, the data was further stratified by ecological unit boundaries to evaluate regional differences in projected trends in climate variables. The results in Table 3.7.2 shows the expected increase in temperature and precipitation for ecological units across California.

Figure 3.7.1.
Ecological sections.
Source: Miles and Goudy, 1997

Discussion

Bioregional Findings

The results from the climate threat index were made for each of the ecological sections. From this data some general patterns emerged at the larger bioregional level. The following section provides a brief summary of the key findings for the major bioregions in California based on model results from the GFDL global climate model using the B1 emissions scenario.

Overall, the maximum daily temperatures during summer months showed the greatest increase in interior ecosections including: Northwestern Basin and Range, Modoc Plateau, Mojave/Sonora/Colorado deserts, Sierra and the Sierra foothill ecosections. Depending on moisture availability, temperature increases combined with strong decreases in precipitation could lead to dramatic shifts in forest composition in later decades. In addition, the expected increases in temperature alone are likely to result in

Table 3.7.2. Climate threat index – expected changes in temperature (Celsius) and precipitation (mm) by ecological units. The analysis is based on the GFDL climate model under the B1 emissions scenario.

Zone	Eco-Section	Temp 2039	Temp 2069	Temp 2099	Precip 2039	Precip 2069	Precip 2099
261A	Central California Coast	0.82	1.3	1.69	24.58	-11.97	-117.9
261B	Southern California Coast	0.84	1.32	1.76	2.64	-40.86	-56.35
262A	Great Valley	0.98	1.55	1.98	21.65	5.64	-49.81
263A	Northern California Coast	0.8	1.3	1.62	66.44	60.46	-73.16
322ABC	Mojave/Sonoran/Colorado Deserts	1.18	1.87	2.3	-1.16	-22.86	-9.62
341DF	Mono, Southeastern Great Basin	1.16	1.9	2.33	8.95	-14.16	-37.84
342B	Northwestern Basin and Range	1.2	1.95	2.41	5.77	-5.26	-29.17
M261ABC	Klamath Mountains, Northern California Coast and Interior Coast Ranges	0.91	1.48	1.85	56.42	43.65	-66.48
M261D	Southern Cascades	1.07	1.74	2.17	37	18.6	-64.22
M261E	Sierra Nevada	1.09	1.76	2.18	70.05	17.57	-110.57
M261F	Sierra Nevada Foothills	1.04	1.65	2.08	49.24	11.07	-96.55
M261G	Modoc Plateau	1.17	1.89	2.34	15.22	-2.53	-32.06
M262A	Central California Coast Ranges	0.94	1.51	1.96	20.27	-5.27	-75.91
M262B	Southern California Mountains and Valleys	1.12	1.77	2.22	-6.3	-54.81	-44.74

Data Source: Climate Change Scenarios; California Energy Commission, 2009

declining snowpack over time, which will affect water resources and related environmental services.

Klamath/North Coast (ecosections: 263A, M261A, M261B, M261C)
Expected increases in temperature that range from 0.8 degrees C (1.6 °F) in 2039 to 1.9 degrees C (3.2 °F) in 2099; the seasonal difference between maximum temperatures in winter and summer months is present, but slight. The pattern for average annual precipitation is variable; showing substantial (more than 60 millimeters) increases through 2069, but then showing large decreases by 2099.

Sierra (ecosections: M261E, M261F)
Expected increases in temperature that range from 1.1 degrees C (1.8 °F) in 2039 to 2.2 degrees C (3.8 °F) in 2099; the seasonal difference between maximum temperatures in winter and summer months is more pronounced than in coastal ecosections. The pattern for average annual precipitation is variable; showing increases through 2069, but then showing a substantial decrease by 2099.

Central Coast and South Coast (ecosections: 261A, 261B, M262A, M262B)
Both bioregions show a nearly identical trend with average annual temperatures increases that range from 0.8 degrees C (1.4 °F) in 2039 to 2.2 degrees C (3.0 °F) in 2099. There are also seasonal differences in the rate of temperature increase. For these bioregions, the maximum temperature during summer months is expected to increase by approximately 0.5 degrees C (0.9 °F) compared to winter maximum temperatures. The interior ecological sections show a more pronounced increase in temperature (approximately 0.5 degrees C (0.9 F)) compared to the direct coastal units. The pattern for average annual precipitation is variable; showing increases through 2039, but then showing a substantial decrease by 2099.

Sacramento and San Joaquin Valleys (ecosections: 262A)
Expected increases in temperature that range from 1.0 degrees C (1.8 °F) in 2039 to 2.0 degrees C (3.6 °F) in 2099; the seasonal difference between maximum temperatures in winter and summer months is more pronounced than in coastal bioregions. The pattern for average annual precipitation is variable;

showing increases through 2069, but then showing a decrease by 2099.

Mojave and Colorado Desert (ecosections: 322A, 322B, 322C)
Expected increases in temperature that range from 1.2 degrees C (2.1 °F) in 2039 to 2.3 degrees C (4.1 °F) in 2099; temperature increase during summer months are expected to increase nearly 3.0 degrees C (5.4 °F) by 2099. Changes in precipitation are slight through 2039, but expected to decline through 2099.

FOREST CARBON

Forest Carbon Accounting

A broad range of methods are being explored to count carbon sequestered and released from forests in California. Initial estimates were developed by the California Energy Commission and later refined by Air Resources Board as part of climate change legislation in California (AB 32) that requires emissions to be reduced to 1990 levels by 2020. These initial estimates show California forests operating as a net sink of approximately five million metric tons of carbon dioxide, taking both removals and emissions into account. Recently, an inter-agency forest working group was formed to address a number of forestry-related issues associated with AB 32, including appropriate methods and agreed upon standards for carbon accounting in the forest sector. In addition, the U.S. Forest Service in Region 5 has conducted an initial inventory of carbon stocks in California. These results show that under a "business as usual" scenario forest carbon will see an overall increase over the next four to six decades before declining to 1990 levels by 2100 (Goines and Nechodom, 2009). The capacity to maintain a carbon sink over time was determined to be dependent on how well national forests can manage risk of losses from wildfire and the effectiveness of implementing strategies to maintain forest health.

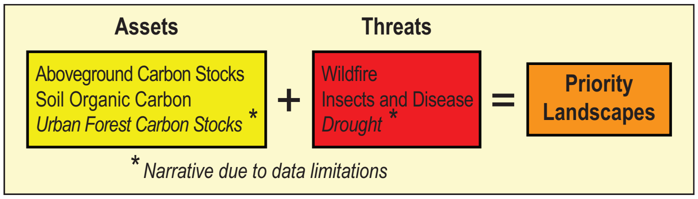
Estimates of forest carbon presented in this chapter are based on a single model (MC1) and are not intended to provide a detailed accounting of forest carbon. Rather, the analysis is intended to highlight areas where forest carbon assets are highest and identify areas that are at greatest risk to losses of forest carbon in the future.

Analysis: Forest Carbon – Threats from Wildfire, Insects and Disease

A broad range of environmental services (e.g., clean water, clean air, soil, wildlife habitat, carbon sequestration, nutrient cycling, recreation) are produced by California forests and are potentially altered or threatened by climate change. Potential impacts on many of these forest assets are discussed earlier in this chapter. In addition, a recent study found expected declines due to climate change for a number of key environmental services; carbon sequestration, forage production, water flows for salmonids, snow recreation, and biodiversity (Shaw et al., 2008). While the analysis presented here is focused on forest carbon, the priority areas identified through this analysis also support many other important environmental services that are not explicitly modeled.

The following section describes the development of data layers that were used to evaluate above and below ground carbon stocks over future time steps. This represents the capacity of forests and rangelands to sequester carbon. In the first analysis, estimates of above and belowground carbon stocks were evaluated against the risks of losing carbon stocks from ecosystem threats (e.g., wildfire, insects and disease).

The use of a vegetation dynamics model allowed stocks to be evaluated for four different time periods that include: 2010, 2020, 2050 and 2100. The ranking of forest carbon considers both the existing carbon sequestration and the expected increases and decreases over time. The analysis was based on a GIS model that combined threats and assets to produce a priority landscape (see diagram below). Above and below ground forest carbon grids were developed at four different time intervals: 2010, 2020, 2050 and 2100. A unique priority landscape was developed at each time step by overlaying threats from wildfire, insects and disease against a composite assets layer that represents forest carbon. The following section describes forest carbon assets, threats to the assets, and the development of the priority landscape.



Assets

Aboveground Carbon Stocks
Forests act as both a sink and a source of carbon dioxide (CO_2). Forests operate as a sink when they remove carbon dioxide from the atmosphere and through photosynthesis convert carbon into plant tissue where it is stored as biomass both above and belowground. When the forest is harvested, burned, destroyed by insects or converted to other land uses, some of the carbon is returned to the atmosphere as carbon dioxide and the forest becomes a source. This is part of a natural cycle where forests periodically store and release carbon back into the atmosphere. A forest can operate as a sink, over a fixed period of time, when carbon sequestration exceeds the release of carbon. It is the net effect of forest management activities and natural disturbances that will determine whether the forest is a sink or a source over time.

Estimates of aboveground carbon stocks were derived from the MC1 dynamic global vegetation model (Table 3.7.3) developed by the U.S. Forest Service and the Forest Sciences Laboratory at Oregon State University. The MC1 model can be used to estimate distribution of broad forest vegetation types, fluxes in forest carbon, nutrients and water. Coupled with climate data from general circulation models (GCMs), the model can simulate expected changes in vegetation under a broad range of climate scenarios. MC1 consists of several sub-modules that simulate interactions between climate and vegetation over time (Bachelet et al., 2003). This model was previously developed and run for California using a range of GCMs under differing emissions scenarios (Shaw et al., 2008). For this analysis forest carbon stocks were estimated using the GFDL GCM for both lower (B1) and higher (A2) emissions scenarios. When compared with other GCM models, the GFDL model tended to predict hotter and drier conditions for California (Cayan, 2006). The MC1 model has been previously used to evaluate the possible effects of future climate scenarios on vegetation in California (Lenihan et al., 2003; Shaw et al., 2009).

Aboveground carbon was estimated for the following time periods: 2010, 2020, 2050 and 2100. The aboveground carbon storage for California was based on the MC1 "climate neutral" dataset. Climate neutral data is defined as not including any extra anthropogenic emissions, and is based on historical mean climate data. The aboveground carbon includes aboveground dead carbon, live tree carbon and live herbaceous carbon based on the MC1 neutral climate outputs in metric tons per hectare. The aboveground carbon data layer was ranked into three groups (high, medium and low) to identify locations where forest carbon is considered a high asset. If the GCM models predicted a loss of carbon then the rank was lowered by a point, and if the model predicted a gain then the rank was raised by a point. If there was no change in total carbon by the model then the carbon rank was not changed. This method of incorporating the amount of change from the climate neutral data is a way to compare the different GCM model results, and it also places additional emphasis on areas that have a substantial carbon stock to begin with.

Soil Organic Carbon
Soil is also an important carbon sink and can be influenced by the same pressures as forest carbon. Like forest carbon, there are a number of natural and anthropomorphic factors that can shift the role of soil from a sink to a source, such as plant growth, rate of decomposition, nutrient cycles, wind, fire, drought, land use and forest management (Lal, 2005).

Soil organic carbon is represented as belowground carbon storage for the following time periods: 2010, 2020, 2050 and 2100. The belowground carbon

Table 3.7.3. Bioregional estimate of aboveground forest carbon in teragrams (Tg) and the percent change from base year. Note: The estimates are based on results from the MC1 vegetation dynamics model using the GFDL GCM for emission scenarios A1 and B2.

Bioregion	Base Year 2010	GFDL A2 2010	GFDL A2 2020	GFDL A2 2050	GFDL A2 2100	GFDL B1 2010	GFDL B1 2020	GFDL B1 2050	GFDL B1 2100
		116.7	115.7	112.3	94.8	115.7	116.5	112.2	100.8
Bay/Delta	117.8	-1%	-2%	-5%	-20%	-2%	-1%	-5%	-14%
	57	55.2	55.9	54.4	43.8	55.1	57.5	56.8	47.2
Central Coast		-3%	-2%	-5%	-23%	-3%	<1%	<-1%	-17%
	9.3	9.3	9.2	8.8	7.7	9.1	9.1	8.4	8.1
Colorado Desert		0%	-1%	-5%	-13%	-2%	-2%	-10%	-13%
Klamath/North	578.1	581.1	580.1	568.7	474.9	572.7	573.7	556.2	525.4
Coast		<1%	<1%	-2%	-18%	-1%	-1%	-4%	-9%
	208.5	209.1	207.5	199.3	142.1	206.3	206.5	206.6	192.9
Modoc		<1%	<-1%	-4%	-32%	-1%	-1%	-1%	-7%
	31	30.9	31	30.2	26	31.1	30.5	29.3	27.6
Mojave		<-1%	0%	-3%	-16%	<1%	-2%	-5%	-11%
	46.5	45.5	45.6	44.1	29.2	44.6	46.8	43.8	35.4
Sacramento Valley		-2%	-2%	-5%	-37%	-4%	1%	-6%	-24%
	14.8	14	13.6	13.8	12.4	14.1	14.2	13.4	12.1
San Joaquin Valley		-5%	-8%	-7%	-16%	-5%	-4%	-9%	-18%
	343.9	343	346	336.7	260.1	339.3	342.2	338.4	326.5
Sierra		<-1%	1%	-2%	-24%	-1%	<-1%	-2%	-5%
	23.5	23.5	23.8	23.7	20.2	23.4	23.6	22.8	22.1
South Coast		0%	1%	1%	-14%	<-1%	<1%	-3%	-6%
	1430	1,428.3	1,428.4	1,392.1	1,111.3	1,411.3	1,420.6	1,387.9	1,298.0
Total		<-1%	<-1%	-3%	-22%	-1%	-1%	-3%	-9%

storage for California was based on the MC1 "climate neutral;" dataset. The belowground carbon includes both dead and live carbon from grass and tree roots. The data is in metric tons per hectare units. Similar to the aboveground carbon data, the belowground storage values were ranked, and then the ranks were adjusted based on whether the GCM model showed an increase or decrease in carbon storage.

Urban Forest Carbon Stocks

The planting of new trees and the maintenance of existing trees in urban areas contributes to carbon sequestration and the reduction of carbon dioxide. In addition, urban trees provide shade that can reduce energy demands during the warm summer months. However, the coarse nature of the grid cells used by MC1 vegetation dynamics model (12km) combined with limitations in the processes represented by the model are not compatible with the finer scale conditions that characterize urban forests. As such, the contribution of urban forests to carbon sequestration was not included in the GIS based model.

Composite Assets

The composite asset dataset is a combination of the aboveground and belowground carbon data combined into a single dataset that represents the total carbon across the state. To support the GIS based model the data is reclassified into four ranks. These ranks were assigned first by applying quantile breaks to the MC1 climate neutral carbon estimates, and then adjusting the ranks by applying an index of the percentage of change between the carbon neutral and GFDL A2 carbon values to account for areas that are expected to experience carbon fluctuations over time. Rank three represents high carbon sequestration, rank two represents medium carbon sequestration, rank one and rank zero represents low carbon sequestration (Figure 3.7.2). The composite asset for carbon sequestration is at four time periods: 2010, 2020, 2050 and 2100. This estimate is derived from

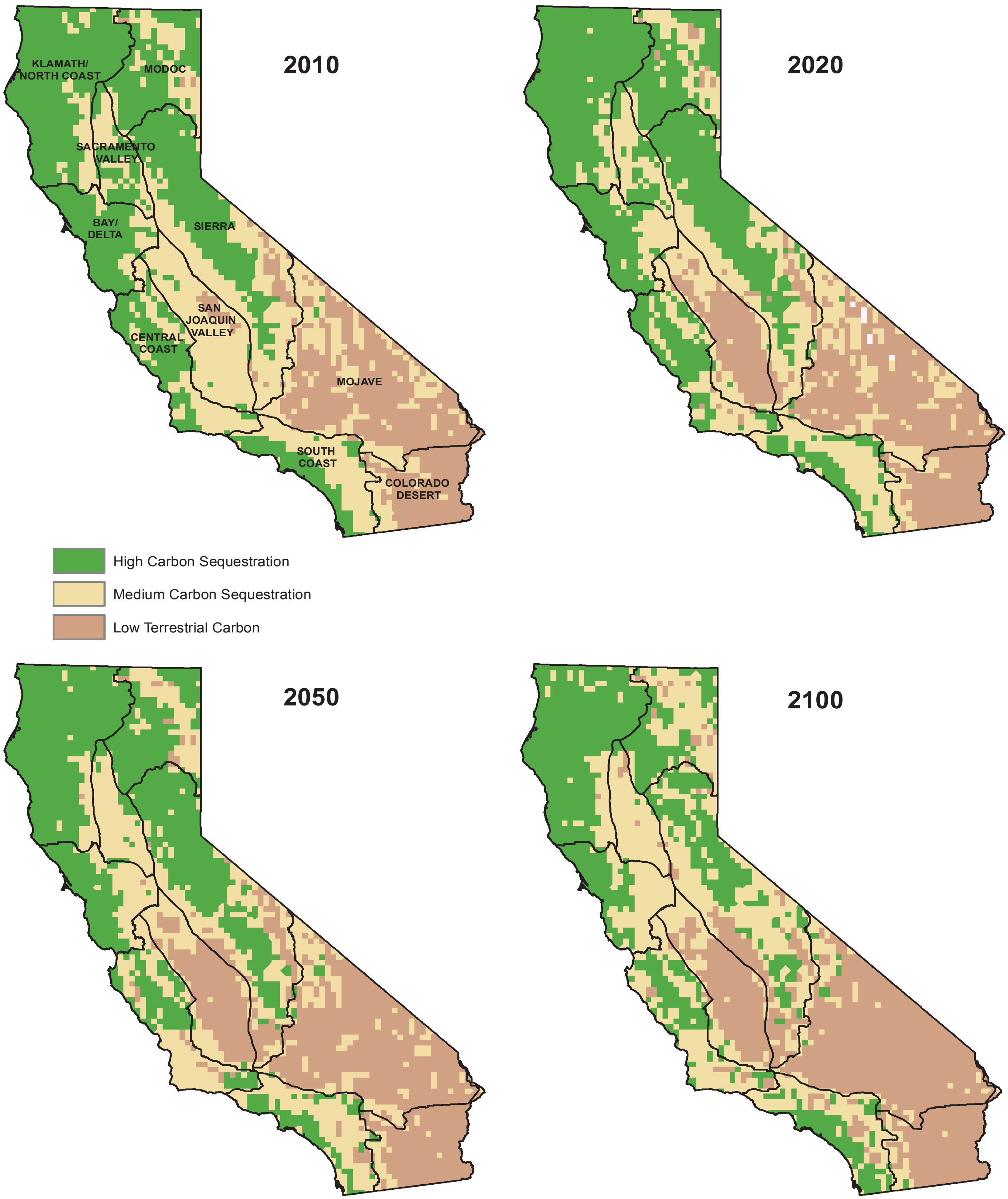


Figure 3.7.2.
Composite forest carbon assets (A2 scenario).
The resulting output is from the MC1 dynamic global vegetation model and is based on climate data from the GFDL GCM under the A2 emissions scenario. Under this scenario forest carbon is relatively stable through 2050.
Data Source: MC1 Dynamic Global Vegetation Model, USFS / Oregon State University / The Nature Conservancy (2009)

the MC1 vegetation dynamics model and is based on climate data from the GFDL GCM under the A2 emissions scenario. Under this scenario forest carbon is relatively stable through 2050. Additional GCM models and emissions scenarios will be evaluated to support future assessments.

Threats

Disturbance resulting in the loss of forest carbon can come from both natural (wildfires, insects, disease) and human related causes (development, deforestation).

Wildfire
Recent research suggests that regardless of the climate model or emissions scenario an increase in wildfire is expected (Westerling et al., 2006). By mid-century the frequency of large wildfires is expected to increase by 30 to 50 percent, and could reach as high as 94 percent by 2085 under the A2 emissions scenario (Westerling, 2009).

Wildfire threat is measured and ranked based on FRAP fire threat data. Fire threat is a combination of two factors: 1) fire frequency, or the likelihood of a given area burning, and 2) potential fire behavior (hazard). These two factors are combined to create four threat classes ranging from moderate to extreme. (See Chapter 2.1 for additional information on threats from wildfire.) This data layer represents a future hazard that is evaluated against the forest carbon assets estimated through the MC1 model at future time period. The MC1 model also incorporates fire, but in a different manner. The MC1 model simulates the occurrence of fire as a disturbance when thresholds for fuel and moisture content are meet. The direct effect of fire simulated in MC1 is on the consumption and mortality of dead and live vegetation carbon, which is removed from the carbon pool at each time step in the model. Lenihan et al. (2006, 2008), provide a more comprehensive discussion of the MC1 fire module. The remaining aboveground carbon pool is then evaluated against the hazard of future fires, represented by the FRAP fire threat layer to determine areas where the remaining aboveground carbon pool is at risk.

Insects and Disease
The loss of carbon stocks from forest health issues, such as outbreaks of insects and disease, can be substantial. These outbreaks can result in direct mortality and increase the risk of high severity wildfires. For this analysis threats from insect and disease outbreaks is used to represent threats to forest health. The threat of damage to ecosystems was evaluated at the stand level and takes a number of factors into account such as severity of damage, the damage causing agent, and how recent the event was with more recent events emphasized over older ones. (See Chapter 2.2 for additional information on threats from forest pests.)

The threat to a particular small area is called the stand-level insect and disease threat, and is based on expected tree mortality over the next 15 years, as developed by the U.S. Forest Service's Forest Health Protection Program (FHP).

Loss of Carbon Stocks from Prolonged Drought
Forests in California and across the western U.S. are periodically under the influence of drought conditions. Many forest species have adaptations that allow them to survive under drought conditions. To the extent that climate change may alter the frequency and severity of drought, forests will likely be adversely affected. Increases in temperature alone may result in decreases in water availability during the dry summer months. Moisture stress from drought can affect plant physiology, productivity, seed production, recruitment and mortality rates (Hansen and Weltzin, 2000).

Results

An overlay of forest carbon assets with the combined threats from wildfire, insects, and disease was done to produce a priority landscape (Figure 3.7.3). The overlay of threats and assets was used to identify where high value carbon stocks coincide with ecosystem threats from wildfire, insects and disease. The resulting priority landscape represents areas where

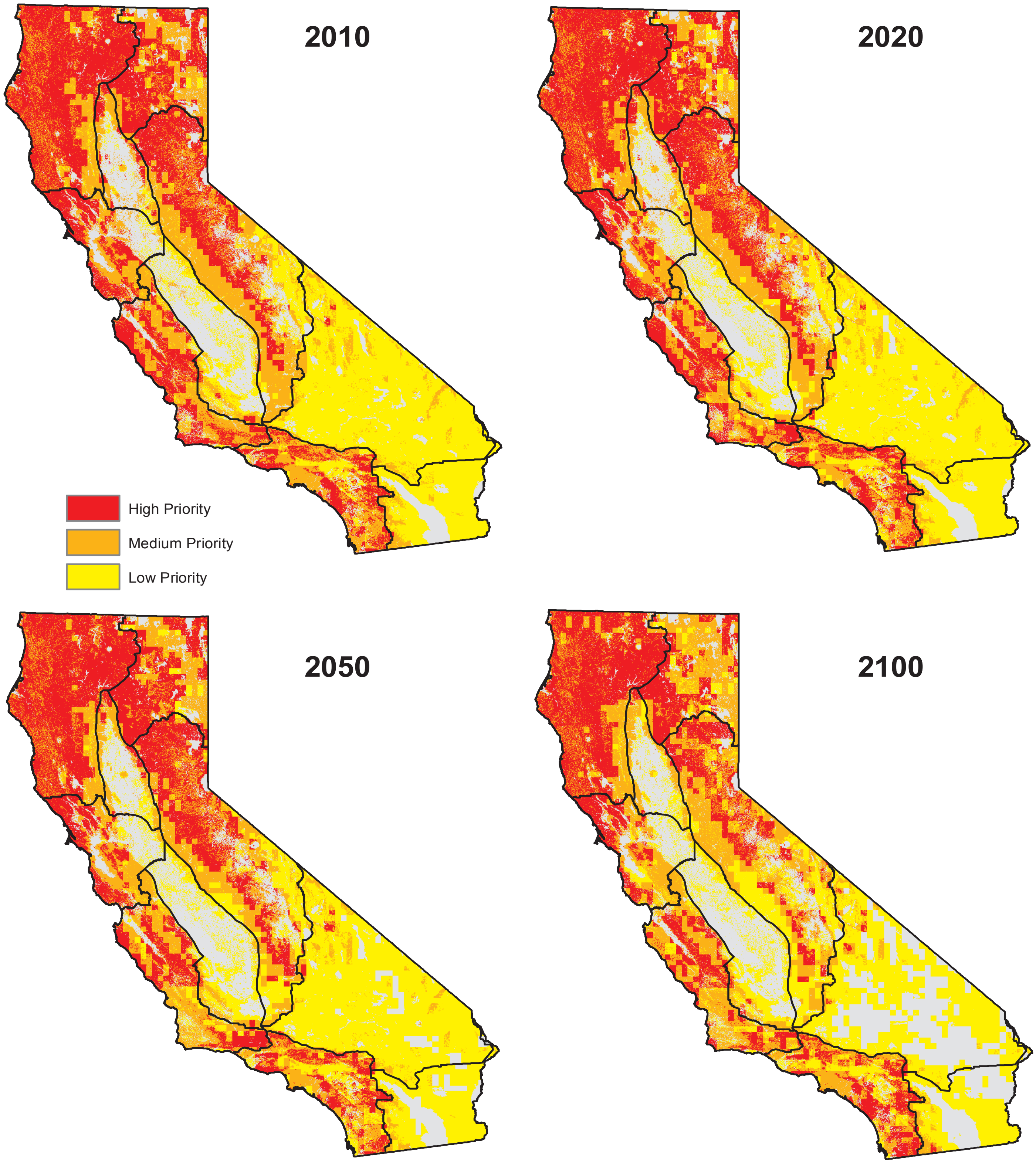


Figure 3.7.3.
Priority landscape forest carbon and ecosystem threat (A2).
The data inputs to the priority landscape were derived from the MC1 vegetation dynamics model and are based on climate data from the GFDL GCM under the A2 emissions scenario. Under this projected climate scenario the priority landscape areas remain relatively stable through 2050.
Data Source: MC1 Dynamic Global Vegetation Model, USFS / Oregon State University / The Nature Conservancy (2009); Forest Pest Risk, USFS FHP (2006 v1); Statewide Land Use / Land Cover Mosaic, FRAP (2006); California Fire Regime Condition Class, FRAP (2003)

high value carbon stocks are at risk. A priority landscape was generated for four different time steps: 2010, 2020, 2050 and 2100. The results for the priority landscape are influenced by both the GCM (GFDL) and the A2 emissions scenario that was used. The composite threat data (insects and wildfire) was not intended to predict as far out as the year 2100, so the results for that year should be considered less reliable than the previous year model outputs.

Results 2010

The evaluation of carbon stocks from the baseline conditions for 2010 showed limited gains or losses in forest carbon stocks. The priority areas are focused predominately on forestlands in the Klamath/North Coast and Sierra bioregions and to a lesser extent for some regional areas in the Central Coast and South Coast bioregions.

Results 2020

The evaluation of carbon stocks from the baseline conditions for 2020 showed limited gains or losses in priority areas compared to 2010. The priority areas remain relatively stable across all bioregions.

Results 2050

An evaluation of carbon stocks from the baseline conditions for 2050 begins to show greater variation in gains or losses in forest carbon stocks when compared to baseline conditions. The warmer and drier conditions forecast through the A2 scenario result in declines in forest carbon in many parts of the state. However, the overall pattern for the priority landscape is similar to previous time periods.

Results 2100

An evaluation of carbon stocks from the baseline conditions for 2100 shows a considerable amount of decline in forest carbon stocks when compared to baseline conditions. The warmer and drier conditions forecast through the A2 scenario result in declines in forest carbon throughout the most of the state.

Discussion

The results from the MC1 vegetation dynamics model, using the GFDL GCM and the A2 emissions scenario, show estimated carbon sequestration across California forests to be relatively stable through 2050. Following 2050, the model shows a dramatic increase in temperature coupled with less precipitation that may result in a substantial decline in forest carbon by 2100. In addition, there are substantial threats to forest carbon from both wildfire and from insects and disease. The implications of the analysis suggest that forests will continue to grow and operate as a carbon sink for several decades, but that in the absence of any changes in management forest carbon will decline in the later decades through 2100. While forests are expected to continue to operate as a carbon sink over the next several decades, if the projected declines in carbon storage in later decades are realized, forests will eventually have a diminished

Table 3.7.4. Summary of acres of medium and high priority landscape (ecosystem threats) by bioregion (acres in thousands). Note: These estimates are based on results from the MC1 vegetation dynamics model.

	2010		2020		2050		2100	
Priority Rank	**Medium**	**High**	**Medium**	**High**	**Medium**	**High**	**Medium**	**High**
Bay/Delta	2,017	2,263	1,979	2,104	2,027	1,934	1,996	1,624
Central Coast	3,344	3,477	3,344	3,477	3,566	2,651	3,893	2,411
Colorado Desert	605	17	605	17	418	51	428	80
Klamath/North Coast	3,688	9,864	3,688	9,864	3,343	10,261	3,766	9,740
Modoc	3,042	3,978	3,042	3,978	2,859	3,975	3,669	2,768
Mojave	1,875	53	1,875	53	1,317	190	980	150
Sacramento Valley	1,171	508	1,171	508	1,108	312	1,061	129
San Joaquin Valley	897	142	897	142	644	89	602	94
Sierra	7,868	5,962	7,868	5,962	6,337	6,352	7,220	3,949
South Coast	3,192	2,454	3,192	2,454	2,817	2,202	2,804	2,404

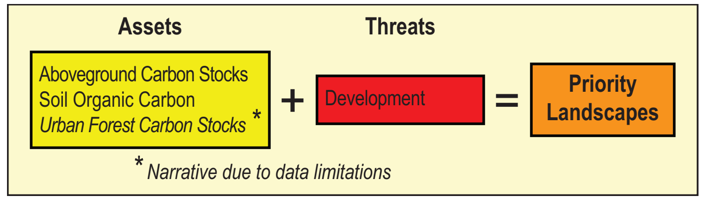
capacity to regulate climate. Maintaining forests as carbon sinks will require policies that address issues related to forest health and strive to lessen the amplitude with which carbon cycles between forests and the atmosphere.

The priority landscape represents the intersection of extensive areas of threats from wildfire and forest pests that coincide with areas that have high carbon sequestration. Priority areas are broadly distributed across forests in the Sierra, Cascades and North Coast ecological sections. There are a range of opportunities to maintain and enhance forest carbon through reforestation, forest management and reduction of losses from wildfire. A further discussion of these and other approaches are found in the strategies report. Overall, the results suggest that managing the risks or threats to loss of forest carbon are equally as important as policies aimed at sequestering additional forest carbon. Management actions and forest policies are needed in high priority areas to reduce risk to loss in forest carbon.

There is considerable uncertainty in the predictions from GCMs and the Dynamic Global Vegetation Model (DGVM), which affect the reliability of predictions from these models. Different assumptions on climate emission scenarios can lead to different trajectories for vegetation dynamics and related ecosystem processes. Ideally, multiple GCMs would be evaluated to bracket the range of possible outcomes. Future assessment work will attempt to incorporate results from other GCMs. Other limitations in DGVMs are that the models use coarse grid cells that do not represent complex topographic changes. In addition, these models typically do not incorporate vegetation changes due to management practices or impacts from insects and disease.

Analysis: Forest Carbon – Threats from Development

The expansion of urban areas, as a result of population growth, can result in conversion of forestlands to other land uses and poses a threat to forest carbon. Estimates of above and belowground carbon stocks were evaluated against patterns of expected development at 2010, 2020, 2050 and 2100. The analysis was based on a GIS model that combines threats and assets to produce a priority landscape.



Asset

Aboveground Carbon Stocks
See above analysis for a description of methods for estimating forest carbon stocks.

Threat

Development
The threat from development is discussed in Chapter 1.1. For this analysis a threat layer was used to represent expected development at future time steps. The GIS data layer depicting future development was created by the EPA as part of the Integrating Climate and Land Use (ICLUS) project (EPA, 2009) and is the result of a demographic model that spatially allocates housing density at decadal time steps.

This data was used to create a statewide development layer for four time steps: 2010, 2020, 2050 and 2100. The area for projected development expanded with each time step. The density of development was assumed to increase over time, which had the effect of increasing the development threat rating for developed areas. For example, an area projected as low density development in 2010 would begin with a low threat rating that would increase at each future time step. The analysis was conducted for the entire state, but the results are difficult to discern on a statewide map. As an example, the progression of development is shown for the Sierra foothill region east of Sacramento (Figure 3.7.4).

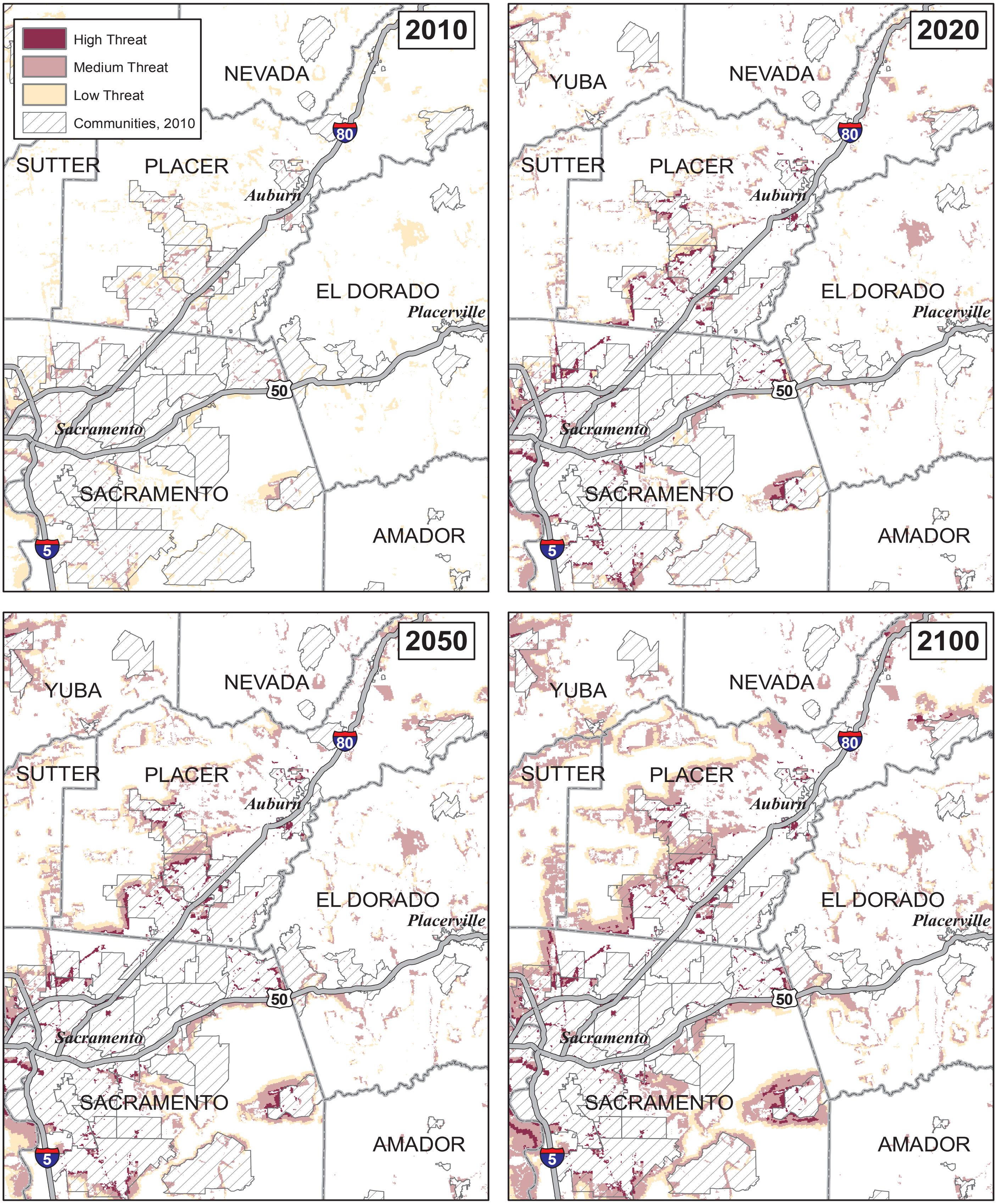


Figure 3.7.4.
Threat to aboveground carbon from projected development.
As development densifies over time, the threat to carbon is expected to increase.
Data Sources: U.S. Census Bureau (2000); ICLUS, U.S. Environmental Protection Agency (2009); Communities, FRAP (2009 v1); Commission on Local Governance for the 21st Century (2000)

Results

Overlaying development threat and forest carbon stocks identified where high value carbon stocks coincide with threats from development that result in the conversion of forests to other land uses. The resulting priority landscape represents areas where high value carbon stocks are at risk. A priority landscape was generated for different time steps: 2010, 2020, 2050 and 2100. The results, shown by bioregion in Table 3.7.5, were influenced by the GFDL GCM used and the B1 and A2 emissions scenarios that were used. An example of the expected changes to the priority landscape over time is given for the Sierra Foothills (Figure 3.7.5). In this region oak woodlands and forests are likely to be at risk to conversion from the progression of development. For additional information on risks to oak woodland and forests see Gaman and Firman (2006).

Results 2010

The priority landscape for 2010 shows priority areas that are largely associated with expanded development around the fringe of existing cities and towns. These newly developed areas are generally associated with a lower level of housing development. As a result most priority areas are listed as low or medium.

Results 2020

The priority landscape for 2020 shows an expansion of priority areas that result from a projected expansion of development. Priority areas that were present in both time periods (2010 and 2020) are likely to have increased in rank. As newly developed areas in 2010 continued to be developed at a higher density there is a greater likelihood of a resulting loss in carbon sequestration. As a result these areas may become a higher priority.

Results 2050

The priority landscape for 2050 shows an expansion in the amount of priority areas that were represented during the 2020 time period. In addition to a greater extent of priority area, those priority areas present in previous time periods (2010 and 2020) are likely to have increased from a lower to higher priority.

Results 2100

The priority areas for 2100 are more speculative. The direction and pattern of development is less certain. However, the 2100 time period shows a continued expansion in priority areas surrounding existing developments.

Discussion

The priority landscape that resulted from the overlay of projected development with aboveground carbon results in a substantial amount of high priority acreage that is expected to increase between 2010 and 2100. The Bay/Delta and South Coast bioregions contain the greatest amount of high priority landscape. In both bioregions high priority areas occupy two to three percent of the bioregion in 2010; by

Table 3.7.5. Summary of high priority landscape (forest carbon and development) by bioregion (acres in thousands). Note: The estimates are based on results from the MC1 vegetation dynamics model. The table summarizes the results for the forest carbon and development analysis.

	2010		2020		2050		2100		Bioregion
Priority Rank	**Medium**	**High**	**Medium**	**High**	**Medium**	**High**	**Medium**	**High**	**Total Acres**
Bay/Delta	192	14	182	173	300	270	533	327	6,292
Central Coast	65	1	86	58	183	76	254	189	7,986
Colorado Desert	6	0	37	6	53	7	106	19	6,757
Klamath/North Coast	36	0	22	37	15	52	19	53	14,383
Modoc	7	0	13	7	15	20	17	30	8,332
Mojave	25	0	76	26	137	26	165	21	19,937
Sacramento Valley	83	13	103	83	194	82	327	66	3,953
San Joaquin Valley	34	1	130	19	183	14	332	28	8,224
Sierra	55	1	93	68	136	94	175	85	18,303
South Coast	137	37	185	167	320	213	409	354	7,059

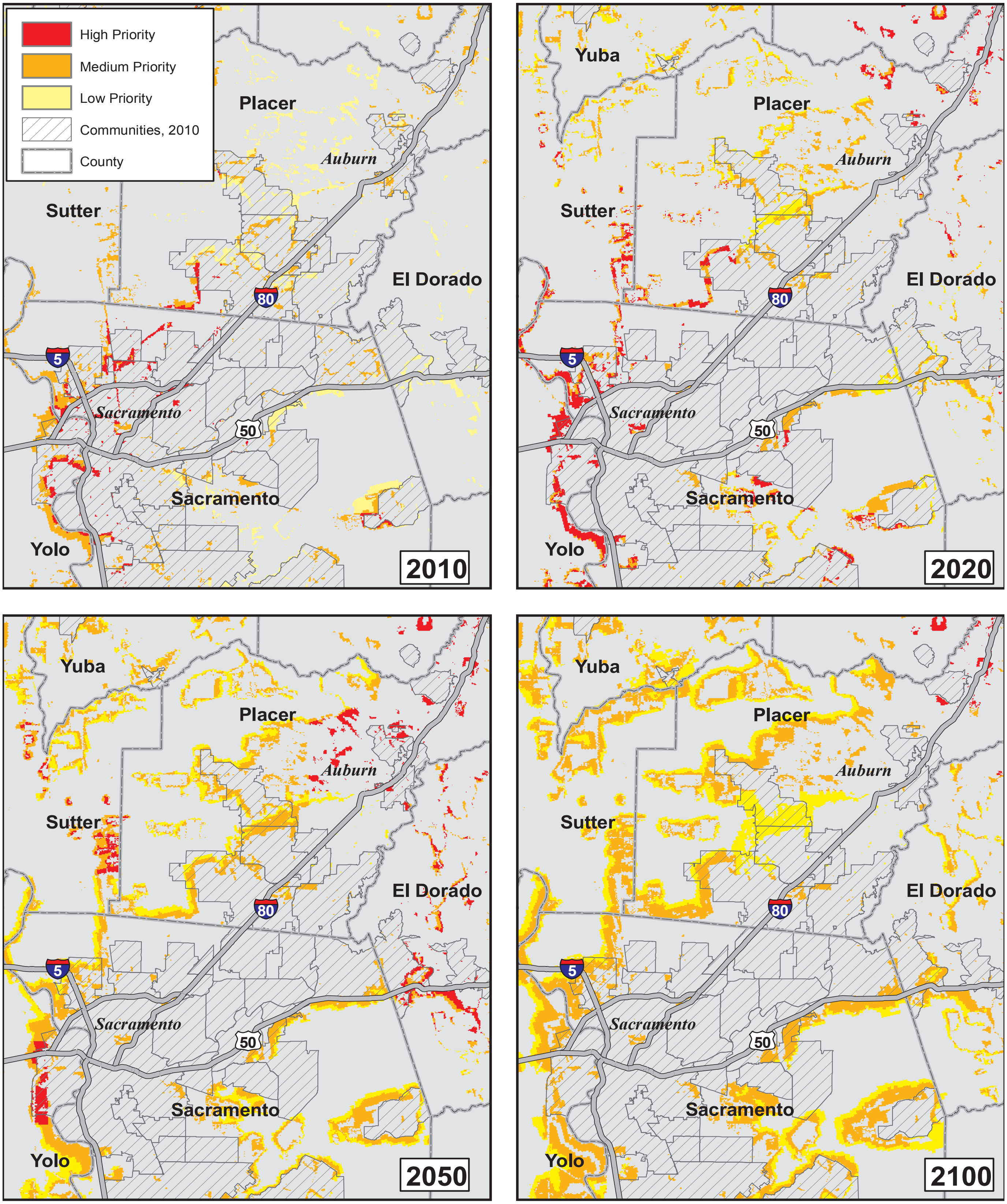


Figure 3.7.5.
Priority landscape for forest carbon (A2) and development.
The data inputs (i.e., forest carbon) to the priority landscape were derived from the MC1 vegetation dynamics model and are based on climate data from the GFDL GCM under the A2 emissions scenario. Areas projected for development in time 2010 can increase in rank as the density of development increases in future decades.
Data Sources: MC1 Dynamic Global Vegetation Model, USFS / Oregon State University / The Nature Conservancy (2009); U.S. Census Bureau (2000); ICLUS, U.S. Environmental Protection Agency (2009); Communities, FRAP (2009 v1); Commission on Local Governance for the 21st Century (2000)

2100 the area is projected to occupy 11 to 14 percent of the bioregion. The Sacramento Valley bioregion showed a similar trend with the amount of high priority landscape starting at two percent in 2010 and projected to increase to 10 percent by 2100. For all other bioregions the amount of high priority landscape was expected to occupy less than five percent of the bioregion.

Policy Options

To preserve and enhance forest carbon management policymakers need to consider both actions that increase carbon sequestration where possible, and actions that reduce losses from wildfire, forest health, land use conversion and other forms of disturbance. Financial incentives to forest landowners (government subsidies and market-based) and regulation are the primary policy tools available to promote sustainable forest management that can contribute to mitigation and adaptation. Regulation must be considered in the context of other interacting factors to be effective; these include leakage (the shifting of emissions elsewhere) where regulatory actions may result in an increase in carbon sequestered by California forests with an unintended increase in emissions elsewhere due to wood imports.

VEGETATION RESPONSE TO CLIMATE CHANGE

The distribution of trees and plants found in forest ecosystems are heavily influenced by temperature and precipitation patterns. The response of forests to changes in climate depends greatly on the availability of water and nutrients. Temperature changes alone can affect plant growing seasons and cause phenological changes in the seasonal timing of flowering and budding (Penuelas and Filella, 2001). As discussed earlier in this chapter, expected changes in future climatic conditions coupled with altered disturbance regimes are likely to result in shifts in species ranges and possible changes in forest productivity. Tree species with the greatest risk of extinction are the ones that are rare and isolated or have fragmented habitats that limit room for migration.

Analysis – Vegetation Response (BioMove)

Through collaboration with researchers from UC Santa Barbara, analysis of potential range shifts using both species distribution models and a vegetation dynamics model called BioMove was conducted for a set of indicator species to evaluate the possible effects of future climate scenarios on the extent and distribution of forest and rangeland vegetation. BioMove is a species-based model for assessing vegetation dynamics that are likely to result under future climate change scenarios.

Species distribution models were constructed using multiple GCMs to capture a broad range of climatic variability based on IPCC climate scenarios. Using climate suitability data from the species distribution models, the BioMove model identified the environmental conditions that could support an individual species under a future climate scenario and evaluated the likelihood of a species occupying the site, given constraints from disturbance and competition. Each model run produced a GIS database that showed the future distribution of individual species. This analysis evaluated the adaptive response of key forest and rangeland species to climate change.

Species Distribution Model

For the species on the indicator list (Table 3.7.6), a species distribution model (SDM) was developed that predicts the range or niche that a species might occupy under future climatic conditions. The SDM assumes that a species range or niche is primarily determined by environmental conditions and that by incorporating predictions from global climate models the shifts in future species range can be predicted (Aitken et al., 2007). As such, the representation of species distribution does not include the constraints from disturbance, competition or dispersal.

The premise behind these models is that environmental conditions are the primary determinant of realized species niches, and that the future preferred range distribution of species can be predicted by transferring the environmental parameters as-

Table 3.7.6. Summary of percent change in species range

Species	Description	Community Climate System Model		Hadley Centre Model	
		Acres	Percent Change	Acres	Percent Change
Red Fir (*Abies Magnifica*)	Gained	53,127	1	494	0
	Lost	4,911,854	77	6,340,092	100
	Stable	1,432,933	23	4,695	0
	Past	6,344,787		6,344,787	
Sugar Pine (*Pinus Lambertiana*)	Gained	6,753,243	61	2,189,059	20
	Lost	383,993	3	3,727,256	34
	Stable	10,709,067	97	7,365,804	66
	Past	11,093,060		11,093,060	
Coulter Pine (*Pinus Coulteri*)	Gained	1,089,958	15	241,664	3
	Lost	5,346,009	75	6,008,978	84
	Stable	1,804,324	25	1,141,355	16
	Past	7,150,333		7,150,333	
Bigcone Douglas-fir (*Pseudotsuga Macrocarpa*)	Gained	3,715,396	63	1,961,233	33
	Lost	1,812,479	31	2,016,089	34
	Stable	4,060,100	69	3,856,490	66
	Past	5,872,579		5,872,579	
Blue Oak (*Quercus Douglasii*)	Gained	975,057	4	4,336,852	16
	Lost	10,008,538	37	7,053,222	26
	Stable	16,965,886	63	19,921,202	74
	Past	26,974,424		26,974,424	
Pasadena Oak (*Quercus Engelmannii*)	Gained	1,220,180	38	2,607,399	82
	Lost	633,317	20	1,160,876	36
	Stable	2,551,802	80	2,024,243	64
	Past	3,185,119		3,185,119	

sociated with the present distribution onto maps representing future climate scenarios.

The results summarize the expected increases and decreases in indicator species range when comparing current range extent to the predicted range in 2080. The species range was developed for two global climate models: the Community Climate System Model (CCSM) developed by National Center for Atmospheric Research and the Hadley Centre Model (HAD) under the higher emissions A2 scenario (Figure 3.7.6). For many species there was strong agreement in the predicted species shift from both models. However, in other cases the model results are quite different. As shown for sugar pine, the CCSM model predicts an expanding range that is influenced by the warmer and wetter conditions. In contrast, hotter and drier conditions forecasted by the Hadley global climate model results in a contraction of the species range.

Discussion

The species distribution models provide an approximation of the degree to which future climatic conditions are likely to alter a species range. This interpretation is based on predictions of climate change derived from two global climate models. These projected shifts in species range are an approximation based solely on expected changes in environmental conditions. The BioMove model will further refine the expected locations that species are likely to occupy by introducing constraints from disturbance, dispersal and competition (Hannah et al., 2008). The shifting of species ranges due to a changing climate has implications for forest management. Environmental conditions may no longer support some species. In other cases management actions may be taken to enhance survival, or protect key refugia based on the expected shift in species range.

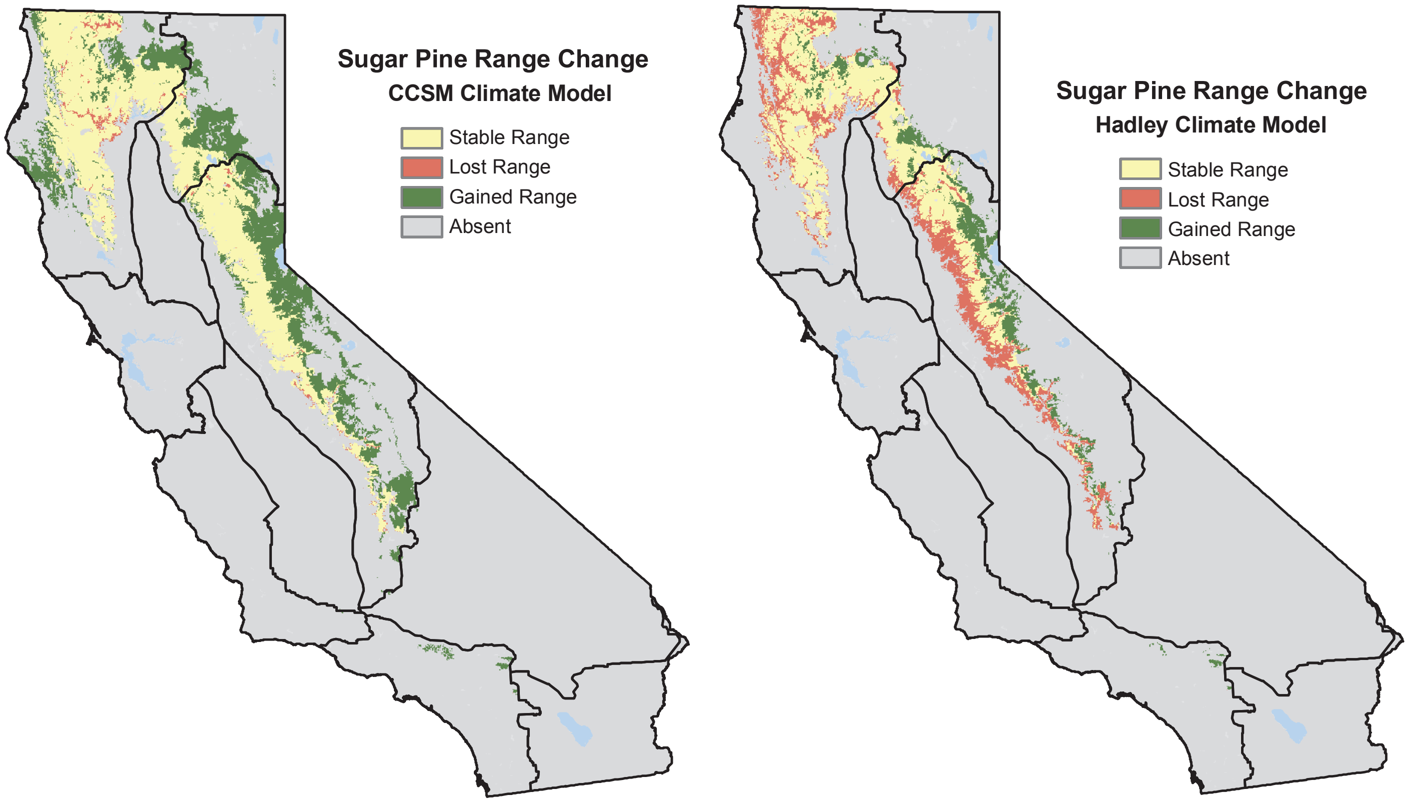


Figure 3.7.6.
Predicted shift in species range for sugar pine.
The map on the left shows an expanding range that is influenced by the warmer and wetter conditions predicted under the CCSM climate model. The map on the right predicts a contraction in species range that is influenced by the hotter and drier conditions forecasted by the Hadley climate model.
Data Sources: BioMove, UC Santa Barbara (2009); California Protected Areas Database (CPAD), GreenInfo Network (2009)