Our Changing Climate

Assessing the Risks to California

A Summary Report from
the California Climate Change Center

Because most global warming emissions remain in the atmosphere for decades or centuries, the choices we make today greatly influence the climate our children and grandchildren inherit. The quality of life they experience will depend on if and how rapidly California and the rest of the world reduce these emissions.

In California and throughout western North America, signs of a changing climate are evident. During the last 50 years, winter and spring temperatures have been warmer, spring snow levels in lower- and mid-elevation mountains have dropped, snowpack has been melting one to four weeks earlier, and flowers are blooming one to two weeks earlier.

These regional changes are consistent with global trends. During the past 100 years, average temperatures have risen more than one degree Fahrenheit worldwide. Research indicates that much of this warming is due to human activities, primarily burning fossil fuels and clearing forests, that release carbon dioxide (CO_2) and other gases into the atmosphere, trapping in heat that would otherwise escape into space. Once in the atmosphere, these heat-trapping emissions remain there for many years—CO_2, for example, lasts about 100 years. As a result, atmospheric concentration of CO_2 has increased more than 30 percent above pre-industrial levels. If left unchecked, by the end of the century CO_2 concentrations could reach levels three times higher than pre-industrial times, leading to dangerous global warming that threatens our public health, economy, and environment.

The latest projections, based on state-of-the art climate models, indicate that if global heat-trapping emissions proceed at a medium to high rate, temperatures in California are expected to rise 4.7 to 10.5°F by the end of the century. In contrast, a lower emissions rate would keep the projected warming to 3 to 5.6°F. These temperature increases would have widespread consequences including substantial loss of snowpack, increased risk of large wildfires, and reductions in the quality and quantity of certain agricultural products. The state's vital resources and natural landscapes are already under increasing stress due to California's rapidly growing population, which is expected to grow from 35 million today to 55 million by 2050.

This document summarizes the recent findings of the California Climate Change Center's "Climate Scenarios" project, which analyzed a range of impacts that projected rising temperatures would likely have on California. The growing severity of the consequences as temperature rises underscores the importance of reducing emissions to minimize further warming. At the same time, it is essential to identify those consequences that may be unavoidable, for which we will need to develop coping and adaptation strategies.

In 2003, the California Energy Commission's Public Interest Energy Research (PIER) program established the California Climate Change Center to conduct 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 as well as the efforts designed to reduce emissions.

Executive Order #S-3-05, signed by Governor Arnold Schwarzenegger on June 1, 2005, called for the California Environmental Protection Agency (CalEPA) to prepare biennial science reports on the potential impact of continued global warming on certain sectors of the California economy. CalEPA entrusted PIER and its California Climate Change Center to lead this effort. The "Climate Scenarios" analysis summarized here is the first of these biennial science reports, and is the product of a multi-institution collaboration among the California Air Resources Board, California Department of Water Resources, California Energy Commission, CalEPA, and the Union of Concerned Scientists.

Cover photos: (sunset) Photos.com; (from top to bottom) AP Photo/Paul Sakuma, iStockphoto, IndexStock, Picturequest, iStockphoto. Above: Bureau of Land Management. Background: IndexStock

California's Future Climate

California's climate is expected to become considerably warmer during this century. How much warmer depends on the rate at which human activities, such as the burning of fossil fuels, continue. The projections presented here illustrate the climatic changes that are likely from three different heat-trapping emissions scenarios (see figure below).

Projected Warming

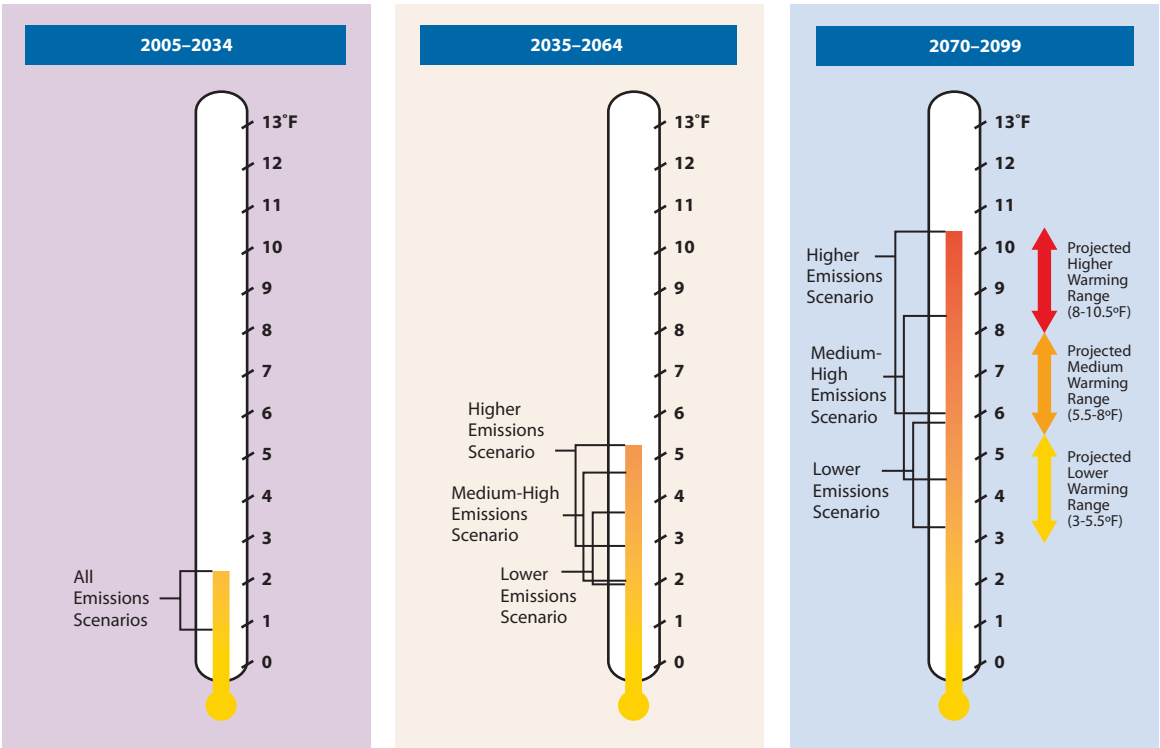
Temperatures are expected to rise substantially in all three emissions scenarios. During the next few decades, the three scenarios project average temperatures to rise between 1 and 2.3°F; however, the projected temperature increases begin to diverge at mid-century so that, by the end of the century, the temperature increases projected in the higher emissions scenario are approximately twice as high as those projected in the lower emissions scenario. Some climate models indicate that warming would be greater in summer than in winter, which would have widespread effects on ecosystem health, agricultural production, water use and availability, and energy demand.

Toward the end of the century, depending on future heat-trapping emissions, statewide average temperatures are expected to rise between 3 and 10.5°F. The analysis presented here examines the future climate under three projected warming ranges:[1]

- **Lower warming range:** projected temperature rises between 3 and 5.5°F
- **Medium warming range:** projected temperature rises between 5.5 and 8°F
- **Higher warming range:** projected temperature rises between 8 and 10.5°F

Precipitation

On average, the projections show little change in total annual precipitation in California. Furthermore, among several models, precipitation projections do not show a consistent trend during the next century. The Mediterranean seasonal precipitation pattern is expected to continue, with most precipitation falling during winter from North Pacific storms. One of the three climate models projects slightly wetter winters, and another projects slightly drier winters with a 10 to 20 percent decrease in total annual precipitation. However, even modest changes would have a significant impact because California ecosystems are conditioned to historical precipitation levels and water resources are nearly fully utilized.



California is expected to experience dramatically warmer temperatures during the 21st century. This figure shows projected increases in statewide annual temperatures for three 30-year periods. Ranges for each emissions scenario represent results from state-of-the-art climate models.

1 These warming ranges are for illustrative purposes only. These ranges were defined in the original Climate Scenarios analysis to capture the full range of projected temperature rise. The exact values for the warming ranges as presented in the original summary report are: lower warming range (3 to 5.4°F); medium warming range (5.5 to 7.9°F); and higher warming range (8 to 10.4°F).

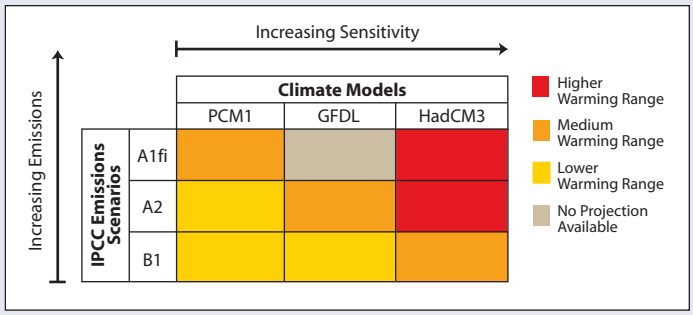
Projecting Future Climate

How much temperatures rise depends in large part on how much and how quickly heat-trapping emissions accumulate in the atmosphere and how the climate responds to these emissions. The projections presented in this report are based on three different heat-trapping emissions scenarios and three climate models.

Emissions Scenarios

The three global emissions scenarios used in this analysis were selected from a set of scenarios developed by the Intergovernmental Panel on Climate Change's (IPCC) *Special Report on Emissions Scenarios*, based on different assumptions about population growth and economic development (measured in gross domestic product).

- The **lower emissions scenario (B1)** characterizes a world with high economic growth and a global population that peaks by mid-century and then declines. There is a rapid shift toward less fossil fuel-intensive industries and introduction of clean and resource-efficient technologies. Heat-trapping emissions peak about mid-century and then decline; CO_2 concentration approximately doubles, relative to pre-industrial levels, by 2100.
- The **medium-high emissions scenario (A2)** projects continuous population growth and uneven economic and technological growth. The income gap between now-industrialized and developing parts of the world does not narrow. Heat-trapping emissions increase through the 21st century; atmospheric CO_2 concentration approximately triples, relative to pre-industrial levels, by 2100.
- The **higher emissions scenario (A1fi)** represents a world with high fossil fuel-intensive economic growth, and a global population that peaks mid-century then declines. New and more efficient technologies are introduced toward the end of the century. Heat-trapping emissions increase through the 21st century; CO_2 concentration more than triples, relative to pre-industrial levels, by 2100.



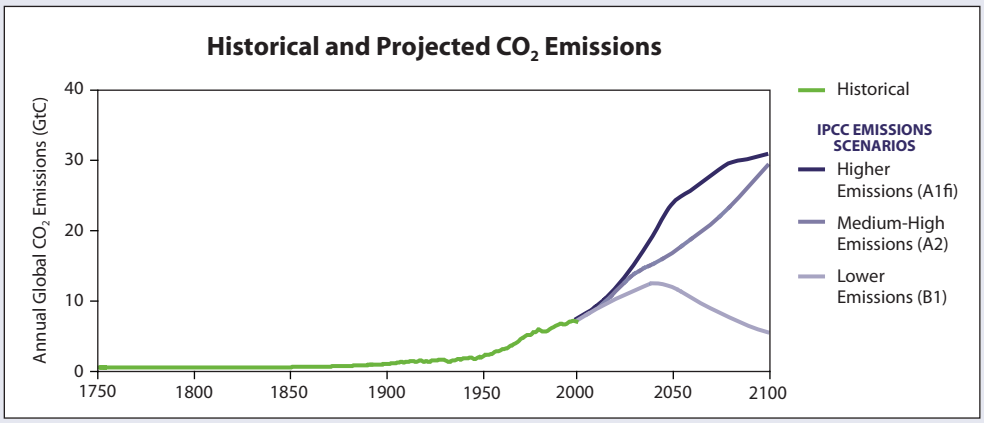
This matrix shows the temperature increases that result from the three climate models, assuming emission inputs indicated in the IPCC emissions scenarios. The resulting temperatures are grouped into three warming ranges defined in the "Climate Scenarios" analysis.

Climate Sensitivity

The three models used in this analysis represent different climate sensitivities, or the extent to which temperatures will rise as a result of increasing atmospheric concentrations of heat-trapping gases. Climate sensitivity depends on Earth's response to certain physical processes, including a number of "feedbacks" that might amplify or lessen warming. For example, as heat-trapping emissions cause temperatures to rise, the atmosphere can hold more water vapor, which traps heat and raises temperatures further—a positive feedback. Clouds created by this water vapor could absorb and re-radiate outgoing infrared radiation from Earth's surface (another positive feedback) or reflect more incoming shortwave radiation from the sun before it reaches Earth's surface (a negative feedback).

Because many of these processes and their feedbacks are not yet fully understood, they are represented somewhat differently in different global climate models. The three global climate models used in this analysis are:

- **National Center for Atmospheric Research Parallel Climate Model (PCM1):** low climate sensitivity
- **Geophysical Fluids Dynamic Laboratory (GFDL) CM2.1:** medium climate sensitivity
- **United Kingdom Met Office Hadley Centre Climate Model, version 3 (HadCM3):** medium-high climate sensitivity



As this figure shows, CO_2 emissions from human activities (such as the burning of fossil fuels) were negligible until around the so-called industrial age starting in the 1850s.

Public Health

Continued global warming will affect Californians' health by exacerbating air pollution, intensifying heat waves, and expanding the range of infectious diseases. The primary concern is not so much the change in *average* climate but the projected increase in *extreme* conditions, which pose the most serious health risks.

Poor Air Quality Made Worse

Californians currently experience the worst air quality in the nation, with more than 90 percent of the population living in areas that violate the state's air quality standard for either ground-level ozone or airborne particulate matter. These pollutants can cause or aggravate a wide range of health problems including asthma and other acute respiratory and cardiovascular diseases, and can decrease lung function in children. Combined, ozone and particulate matter contribute to 8,800 deaths and $71 billion in healthcare costs every year. If global background ozone levels increase as projected in some scenarios, it may become impossible to meet local air quality standards.

Higher temperatures are expected to increase the frequency, duration, and intensity of conditions conducive to air pollution formation. For example, if temperatures rise to the medium warming range, there will be 75 to 85 percent more days with weather conducive to ozone formation in Los Angeles and the San Joaquin Valley, relative to today's conditions. This is more than twice the increase expected if temperature rises are kept in the lower warming range.

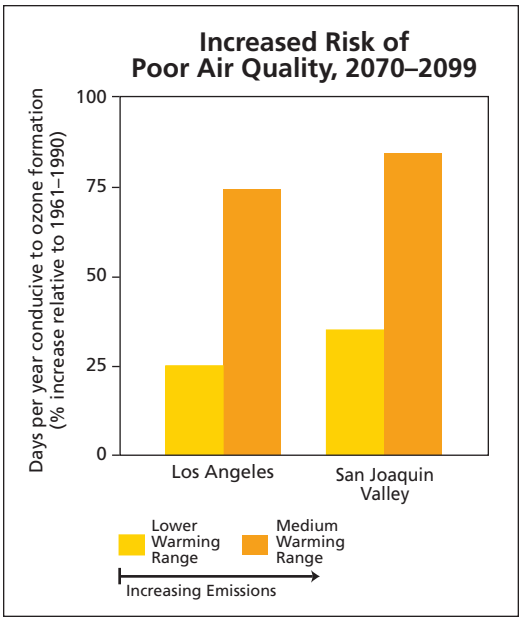
Air quality could be further compromised by increases in wildfires, which emit fine particulate matter that can travel long distances depending on wind conditions. The most recent analysis suggests that if heat-trapping gas emissions are not significantly reduced, large wildfires could become up to 55 percent more frequent toward the end of the century.

More Severe Heat

By 2100, if temperatures rise to the higher warming range, there could be up to 100 more days per year with temperatures above 90°F in Los Angeles and above 95°F in Sacramento. This is a striking increase over historical patterns (see chart on p. 6), and almost twice the increase projected if temperatures remain within or below the lower warming range.

As temperatures rise, Californians will face greater risk of death from dehydration, heat stroke/exhaustion, heart attack, stroke, and respiratory distress caused by extreme heat. By mid century, extreme heat events in urban centers such as Sacramento, Los Angeles, and San Bernardino could cause two to three times more heat-related deaths than occur today. The members of the population most vulnerable to the effects of extreme heat include people who are already ill; children; the elderly;

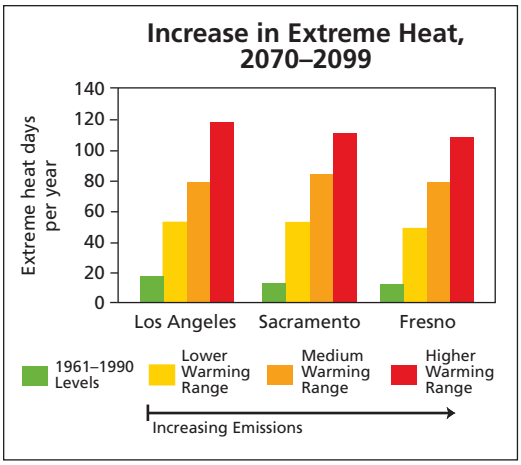
As temperatures rise, Californians will face greater risk of death from dehydration, heat stroke, heart attack, and other heat-related illnesses.



Cars and power plants emit pollutants that contribute to global warming and poor air quality. As temperatures increase, it will be increasingly difficult to meet air quality standards throughout the state.

and the poor, who may lack access to air conditioning and medical assistance.

More research is needed to better understand the potential effects of higher temperatures and the role that adaptation can play in minimizing these effects. For example, expanding air conditioner use can help people cope with extreme heat; however, it also increases energy consumption, which, using today's fossil fuel-heavy energy sources, would contribute to further global warming and air pollution.



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Water Resources

If global warming emissions continue unabated, Sierra Nevada snowpack could decline 70 to 90 percent, with cascading effects on winter recreation, water supply, and natural ecosystems.

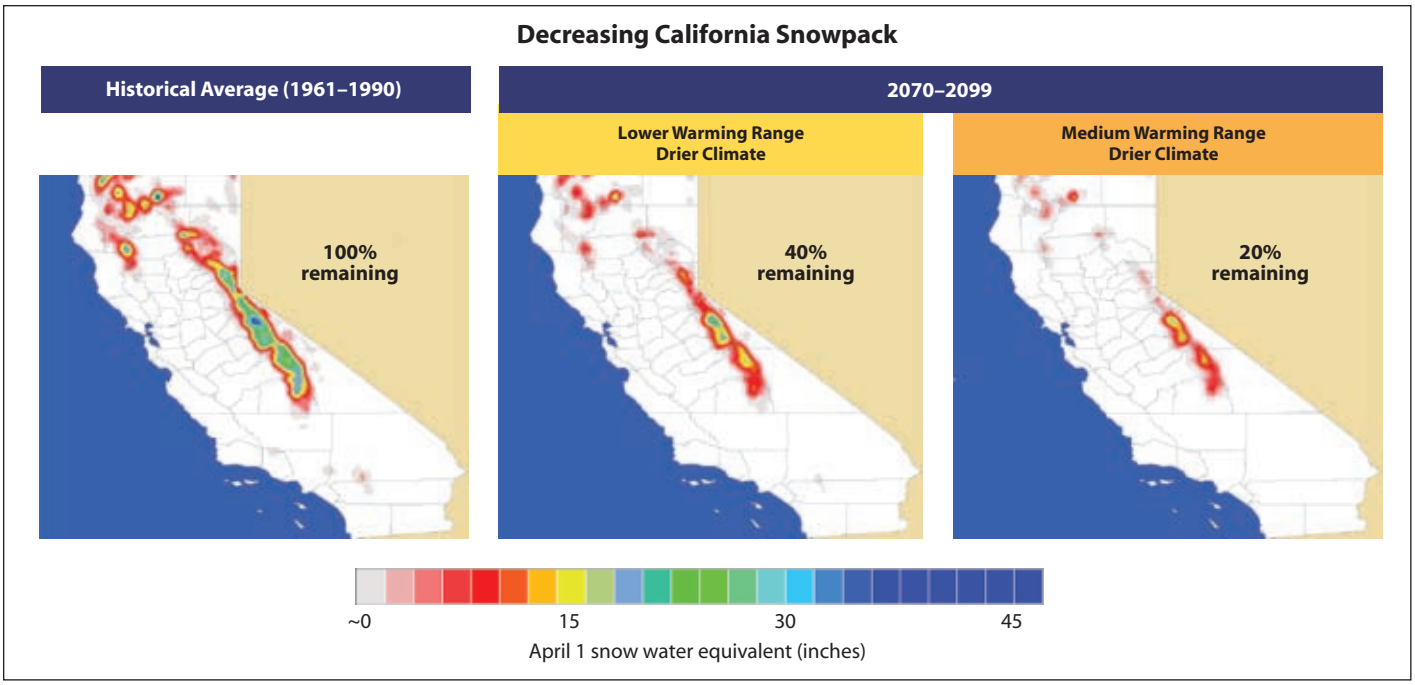
Most of California's precipitation falls in the northern part of the state during the winter while the greatest demand for water comes from users in the southern part of the state during the spring and summer. A vast network of man-made reservoirs and aqueducts capture and transport water throughout the state from northern California rivers and the Colorado River. The current distribution system relies on Sierra Nevada mountain snowpack to supply water during the dry spring and summer months. Rising temperatures, potentially compounded by decreases in precipitation, could severely reduce spring snowpack, increasing the risk of summer water shortages.

Decreasing Sierra Nevada Snowpack

If heat-trapping emissions continue unabated, more precipitation will fall as rain instead of snow, and the snow that does fall will melt earlier, reducing the Sierra Nevada spring snowpack by as much as 70 to 90 percent. How much snowpack will be lost depends in part on future precipitation patterns, the projections for which remain uncertain. However, even under wetter climate projections, the loss of snowpack would pose challenges to water managers, hamper hydropower generation, and nearly eliminate skiing and other snow-related recreational activities. If global warming emissions are significantly curbed and temperature increases are kept in the lower warming range, snowpack losses are expected to be only half as large as those expected if temperatures were to rise to the higher warming range.

Challenges in Securing Adequate Water Supplies

Continued global warming will increase pressure on California's water resources, which are already over-stretched by the demands of a growing



economy and population. Decreasing snowmelt and spring stream flows coupled with increasing demand for water resulting from both a growing population and hotter climate could lead to increasing water shortages. By the end of the century, if temperatures rise to the medium warming range and precipitation decreases, late spring stream flow could decline by up to 30 percent. Agricultural areas could be hard hit, with California farmers losing as much as 25 percent of the water supply they need.

Water supplies are also at risk from rising sea levels. An influx of saltwater would degrade California's estuaries, wetlands, and groundwater aquifers. In particular, saltwater intrusion would threaten the quality and reliability of the major state fresh water supply that is pumped from the southern edge of the Sacramento/San Joaquin River Delta.

Coping with the most severe consequences of global warming would require major changes in water management and allocation systems. As more winter precipitation falls as rain instead of snow, water managers will have to balance the need to fill constructed reservoirs for water supply and the need to maintain reservoir space for winter flood control. Some additional storage could be developed; however, the economic and environmental costs would be high.

Left: Photodisc. Right: Corbis

Rising temperatures, potentially exacerbated by decreasing precipitation, could increase the risk of water shortages in urban and agricultural sectors.

Potential Reduction in Hydropower

Higher temperatures will likely increase electricity demand due to higher air conditioning use. Even if the population remained unchanged, toward the end of the century annual electricity demand could increase by as much as 20 percent if temperatures rise into the higher warming range. (Implementing aggressive efficiency measures could lower this estimate.)

At the same time, diminished snow melt flowing through dams will decrease the potential for hydropower production, which now comprises about 15 percent of California's in-state electricity production. If temperatures rise to the medium warming range and precipitation decreases by 10 to 20 percent, hydropower production may be reduced by up to 30 percent. However, future precipitation projections are quite uncertain so it is possible that precipitation may increase and expand hydropower generation.

Loss of Winter Recreation

Continued global warming will have widespread implications for winter tourism. Declines in Sierra Nevada snowpack would lead to later starting and earlier closing dates of the ski season. Toward the end of the century, if temperatures rise to the lower warming range, the ski season at lower and middle elevations could shorten by as much as a month. If temperatures reach the higher warming range and precipitation declines, there might be many years with insufficient snow for skiing and snowboarding.

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Stephen McMillan

Agriculture

California is home to a $30 billion agriculture industry that employs more than one million workers. It is the largest and most diverse agriculture industry in the nation, producing more than 300 commodities including half the country's fruits and vegetables. Increased heat-trapping emissions are expected to cause widespread changes to this industry, reducing the quantity and quality of agricultural products statewide.

Although higher carbon dioxide levels can stimulate plant production and increase plant water-use efficiency, California farmers will face greater water demand for crops and a less reliable water supply as temperatures rise. Crop growth and development will change, as will the intensity and frequency of pest and disease outbreaks. Rising temperatures will likely aggravate ozone pollution, which makes plants more susceptible to disease and pests and interferes with plant growth.

To prepare for these changes, and to adapt to changes already under way, major efforts will be needed to move crops to new locations, respond to climate variability, and develop new cultivars and agricultural technologies. With adequate research and advance preparation, some of the consequences could be reduced.

Increasing Temperature

Plant growth tends to be slow at low temperatures, increasing with rising temperatures up to a threshold. However, faster growth can result in less-than-optimal development for many crops, so rising temperatures are likely to worsen the quantity and quality of yield for a number of California's agricultural products. Crops that are likely to be hard hit include:

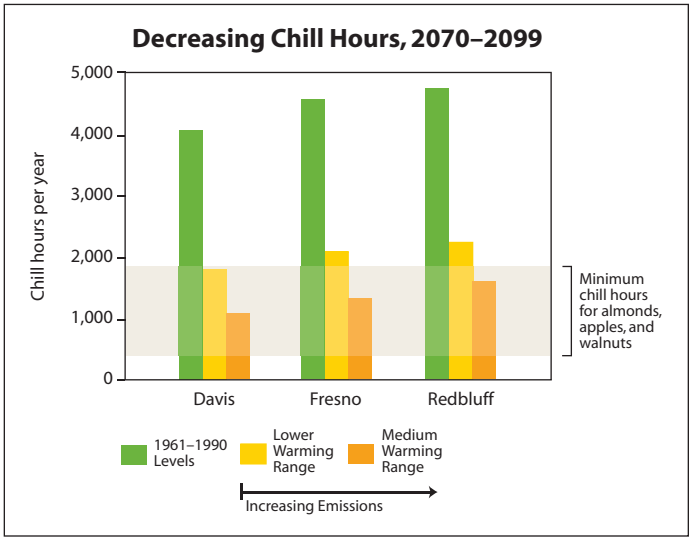
Wine Grapes

California is the nation's largest wine producer and the fourth-largest wine producer worldwide. High-quality wines produced throughout the Napa and Sonoma Valleys and along the northern and central coasts generate $3.2 billion in revenue each year. High temperatures during the growing season can cause premature ripening and reduce grape quality. Temperature increases are expected to have only modest effect on grape quality in most regions over the next few decades. However, toward the end of the century, wine grapes could ripen as much as one to two months earlier, which will affect grape quality in all but the coolest coastal locations (Mendocino and Monterey Counties).

IndexOpen

Fruits and Nuts

Many fruit and nut trees are particularly sensitive to temperature changes because of heat-accumulation limits and chill-hour requirements. Heat accumulation, which refers to the total hours during which temperatures reach between 45 and 95°F, is critical for fruit development. Rising temperatures could increase fruit development rates and decrease fruit size.



For example, peaches and nectarines developed and were harvested early in 2004 because of warm spring temperatures. The fruits were smaller than normal, which placed them in a lower quality category.

A minimum number of chill hours (hours during which temperatures drop below 45°F) is required for proper bud setting; too few hours can cause late or irregular bloom, decreasing fruit quality and subsequent marketable yield. California is currently classified as a moderate to high chill-hour region, but chill hours are diminishing in many areas of the state. If temperatures rise to the medium warming range, the number of chill hours in the entire Central Valley is expected to approach a critical threshold for some fruit trees.

Milk

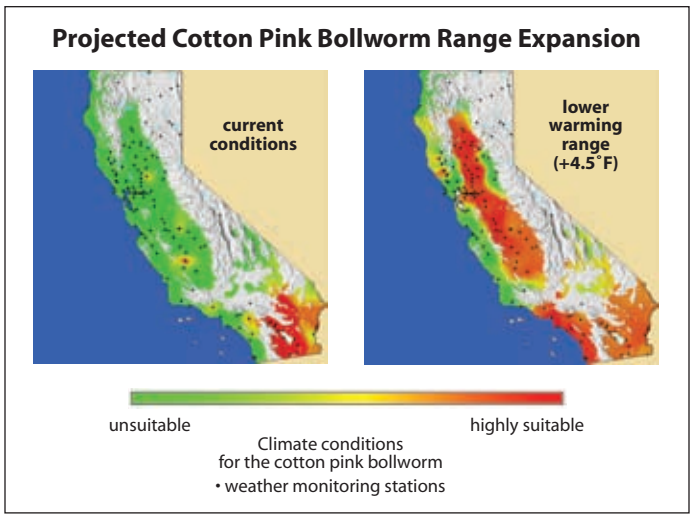
California's $3 billion dairy industry supplies nearly one-fifth of the nation's milk products. High temperatures can stress dairy cows, reducing milk production. Production begins to decline at temperatures as low as 77°F and can drop substantially as temperatures climb above 90°F. Toward the end of the century, if temperatures rise to the higher warming range, milk production is expected to decrease by up to 20 percent. This is more

Increasing temperatures will likely decrease the quantity and quality of some agricultural commodities, such as certain varieties of fruit trees, wine grapes, and dairy products.

than twice the reduction expected if temperatures stay within or below the lower warming range.

Expanding Ranges of Agricultural Weeds

Noxious and invasive weeds currently infest more than 20 million acres of California farmland, costing hundreds of millions of dollars annually in control measures and lost productivity. Continued climate change will likely shift the ranges of existing invasive plants and weeds and alter competition patterns with native plants. Range expansion is expected in many species while range contractions are less likely in rapidly evolving species with significant populations already established. Should range contractions occur, it is likely that new or different weed species will fill the emerging gaps.



Increasing Threats from Pests and Pathogens

California farmers contend with a wide range of crop-damaging pests and pathogens. Continued climate change is likely to alter the abundance and types of many pests, lengthen pests' breeding season, and increase pathogen growth rates. For example, the pink bollworm, a common pest of cotton crops, is currently a problem only in southern desert valleys because it cannot survive winter frosts elsewhere in the state. However, if winter temperatures rise 3 to 4.5°F, the pink bollworm's range would likely expand northward, which could lead to substantial economic and ecological consequences for the state.

Temperature is not the only climatic influence on pests. For example, some insects are unable to cope in extreme drought, while others cannot survive in extremely wet conditions. Furthermore, while warming speeds up the lifecycles of many insects, suggesting that pest problems could increase, some insects may grow more slowly as elevated CO_2 levels decrease the protein content of the leaves on which they feed.

Multiple and Interacting Stresses

Although the effects on specific crops of individual factors (e.g., temperatures, pests, water supply) are increasingly well understood, trying to quantify interactions among these and other environmental factors is challenging. For example, the quality of certain grape varieties is expected to decline as temperatures rise. But the wine-grape industry also faces increasing risks from pests such as the glassy-winged sharpshooter, which transmits Pierce's disease. In 2002, this bacterial disease caused damage worth $13 million in Riverside County alone. The optimum temperature for growth of Pierce's disease is 82°F, so this disease is currently uncommon in the cooler northern and coastal regions of the state. However, with continued warming, these regions may face increased risk of the glassy-winged sharpshooter feeding on leaves and transmitting Pierce's disease.

U.S. Dept. of Agriculture

As temperatures rise, the climate is expected to become more favorable for the pink bollworm (above), a major cotton pest in southern California. The pink bollworm's geographic range is limited by winter frosts that kill over-wintering dormant larvae. As temperatures rise, winter frosts will decrease, greatly increasing the winter survival and subsequent spread of the pest throughout the state.

Forests and Landscapes

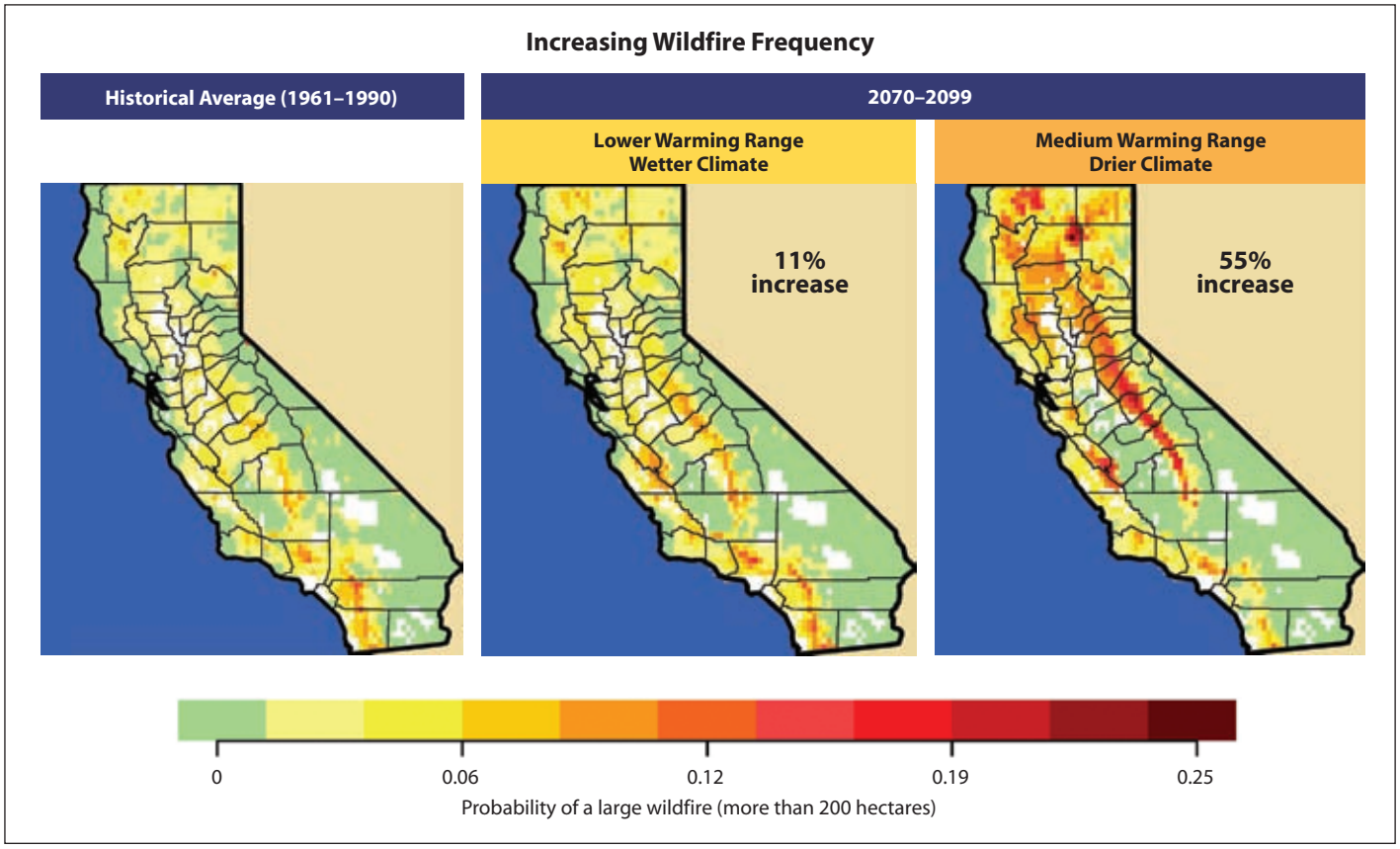
California is one of the most climatically and biologically diverse areas in the world, supporting thousands of plant and animal species. The state's burgeoning population and consequent impact on local landscapes is threatening much of this biological wealth. Global warming is expected to intensify this threat by increasing the risk of wildfire and altering the distribution and character of natural vegetation.

Global warming threatens alpine and subalpine ecosystems, which have no place to move as temperatures rise.

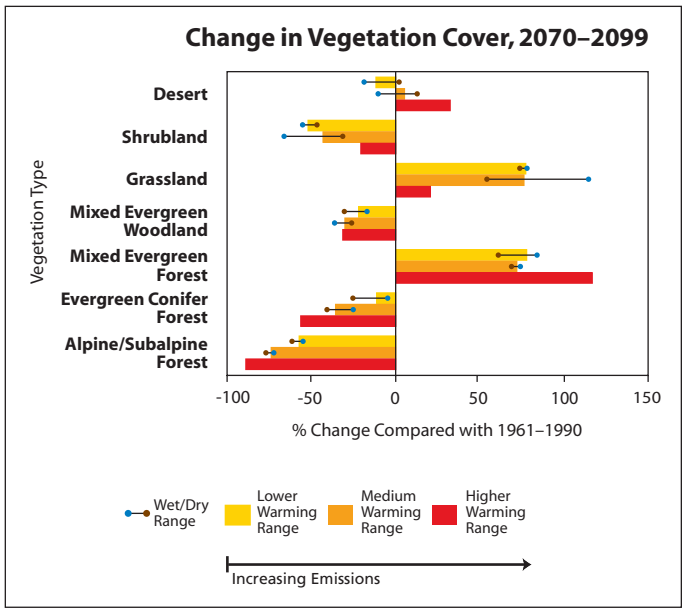
Increasing Wildfires

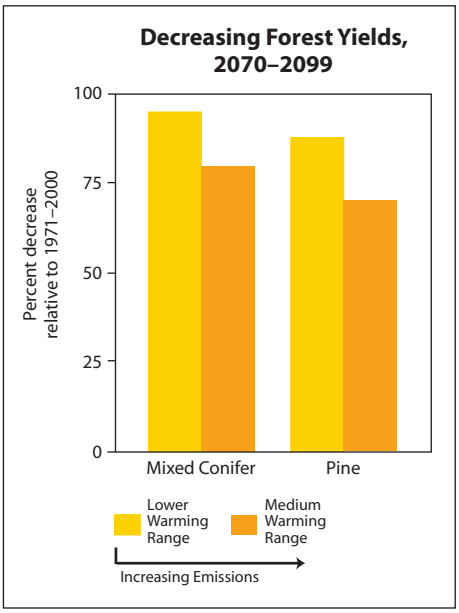
Fire is an important ecosystem disturbance. It promotes vegetation and wildlife diversity, releases nutrients into the soil, and eliminates heavy accumulation of underbrush that can fuel catastrophic fires. However, if temperatures rise into the medium warming range, the risk of large wildfires in California could increase by as much as 55 percent, which is almost twice the increase expected if temperatures stay in the lower warming range.

Because wildfire risk is determined by a combination of factors including precipitation, winds, temperature, and landscape and vegetation conditions, future risks will not be uniform throughout the state. In many regions, wildfire activity will depend critically on future precipitation patterns. For



Vegetation cover over the 21st century will depend on both temperature and precipitation. The lower and medium warming range bars reflect vegetation cover under a wetter climate (blue) and a drier climate (brown) projected in the different climate models. For the higher warming range, only a drier climate was considered.





example, if precipitation increases as temperatures rise, wildfires in the grasslands and chaparral ecosystems of southern California are expected to increase by approximately 30 percent toward the end of the century because more winter rain will stimulate the growth of more plant "fuel" available to burn in the fall. In contrast, a hotter, drier climate could promote up to 90 percent more northern California fires by the end of the century by drying out and increasing the flammability of forest vegetation.

Shifting Vegetation

Land use and other changes resulting from economic development are altering natural habitats throughout the state. Continued global warming will intensify these pressures on the state's natural ecosystems and biological diversity. For example, in northern California, warmer temperatures are expected to shift dominant forest species from Douglas and White Fir to madrone and oaks. In inland regions, increases in fire frequency are expected to promote expansion of grasslands into current shrub and woodland areas. Alpine and subalpine ecosystems are among the most threatened in the state; plants suited to these regions have limited opportunity to migrate "up slope" and are expected to decline by as much as 60 to 80 percent by the end of the century as a result of increasing temperatures.

Declining Forest Productivity

Forestlands cover 45 percent of the state; 35 percent of this is commercial forests such as pine plantations. Recent projections suggest that continued global warming could adversely affect the health and productivity of California's forests. If average statewide temperatures rise to the medium warming range, the productivity of mixed conifer forests is expected to diminish by as much as 18 percent by the end of the century. Yield reductions from pine plantations are expected to be even more severe, with up to a 30 percent decrease by the end of the century.

The risk of large wildfires in California could increase by as much as 55 percent.

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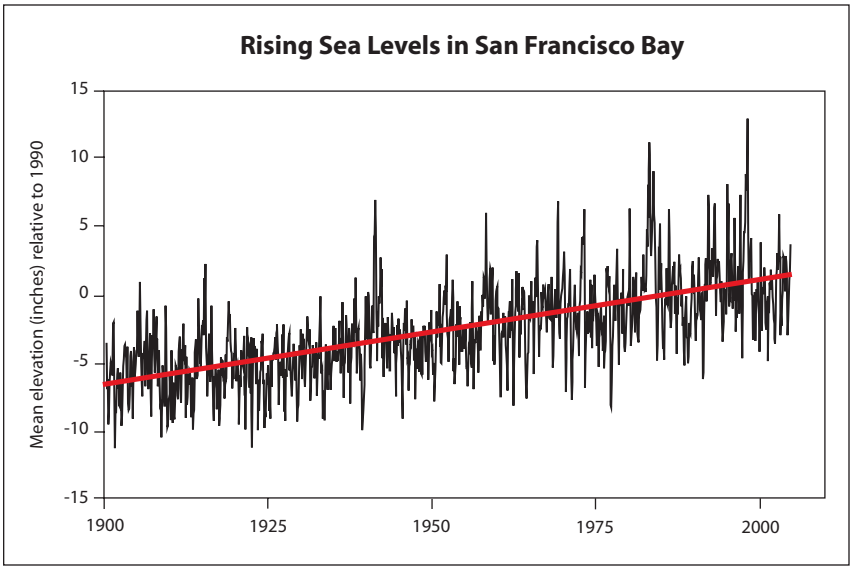
Rising Sea Levels

California's 1,100 miles of coastline are a major attraction for tourism, recreation, and other economic activity. The coast is also home to unique ecosystems that are among the world's most imperiled. As global warming continues, California's coastal regions will be increasingly threatened by rising sea levels, more intense coastal storms, and warmer water temperatures.

During the past century, sea levels along California's coast have risen about seven inches. If heat-trapping emissions continue unabated and temperatures rise into the higher warming range, sea level is expected to rise an additional 22 to 35 inches by the end of the century. Elevations of this magnitude would inundate coastal areas with salt water, accelerate coastal erosion, threaten vital levees and inland water systems, and disrupt wetlands and natural habitats.



Increasing Coastal Floods

The combination of increasingly severe winter storms, rising mean sea levels, and high tides is expected to cause more frequent and severe flooding, erosion, and damage to coastal structures. Many California coastal areas are at significant risk for flood damage. For example, the city of Santa Cruz is built on the 100-year floodplain and is only 20 feet above sea level. Although levees have been built to contain the 100-year flood, a 12-inch increase in sea levels (projected for the medium warming range of temperatures) would mean storm-surge-induced flood events at the 100-year level would likely occur once every 10 years.

Flooding can create significant damage and enormous financial losses. Despite extensive engineering efforts, major floods have repeatedly breached levees that protect freshwater supplies and islands in the San Francisco Bay Delta as well as fragile marine estuaries and wetlands throughout the

Robert A. Epplett/CA Governor's Office of Emergency Services

Rising sea levels and more intense storm surges could increase the risk for coastal flooding.

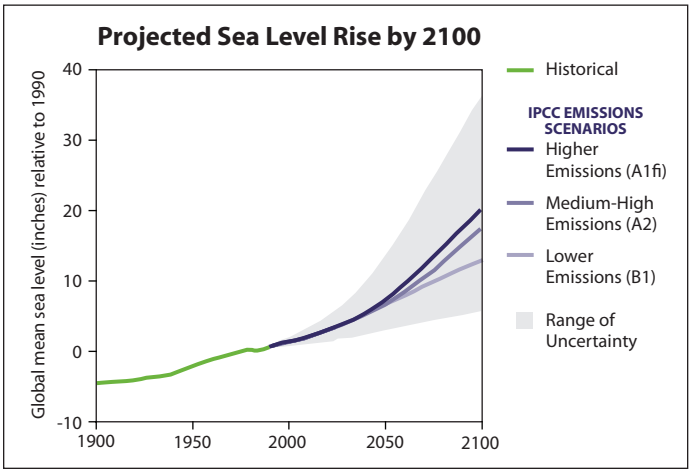
Sea levels could rise up to three feet by the end of the century, accelerating coastal erosion, threating vital levees, and disrupting wetlands.

iStockphoto

Many California beaches are threatened from rising sea levels and increased erosion, an expected consequence of continued global warming.

state. Continued sea level rise will further increase vulnerability to levee failures. Some of the most extreme flooding during the past few decades has occurred during El Niño winters, when warmer waters fuel more intense storms. During the winters of 1982–1983 and 1997–1998, for example, abnormally high seas and storm surges caused millions of dollars' worth of damage in the San Francisco Bay area. Highways were flooded as six-foot waves crashed over waterfront bulkheads, and valuable coastal real estate was destroyed.

Continued global warming will require major changes in flood management. In many regions such as the Central Valley, where urbanization and limited river channel capacity already exacerbate rising flood risks, flood damage and flood control costs could amount to several billion dollars.



Shrinking Beaches

Many of California's beaches may shrink in the future because of rising seas and increased erosion from winter storms. Currently, many beaches are protected from erosion through manmade sand replenishment (or "nourishment") programs, which bring in sand from outside sources to replace the diminishing supply of natural sand. In fact, many of the wide sandy beaches in southern California around Santa Monica, Venice, and Newport Beach were created and are maintained entirely by sand nourishment programs. As sea levels rise, increasing volumes of replacement sand will be needed to maintain current beach width and quality. California beach nourishment programs currently cost millions of dollars each year. As global warming continues, the costs of beach nourishment programs will rise, and in some regions beach replenishment may no longer be viable.

Multiple Causes of Coastal Flooding

Several factors play a role in sea level and coastal flooding, including tides, waves temperature, and storm activity. Sea levels fluctuate daily, monthly, and seasonally; the highest tides occur in winter and in summer, during new and full moons. Sea levels often rise even higher during El Niño winters, when the Eastern Pacific Ocean is warmer than usual and westerly wind patterns are strengthened.

Coastal flooding usually occurs during winter storms, which bring strong winds and high waves. Storm winds tend to raise water levels along the coast and produce high waves at the same time, compounding the risk of damaging waves—a doubling of wave height is equivalent to a four-fold increase in wave energy. When these factors coincide with high tides, the chances for coastal damage are greatly heightened.

As sea levels rise, flood stages in the Sacramento/San Joaquin Delta of the San Francisco Bay estuary may also rise, putting increasing pressure on Delta levees. This threat may be particularly significant because recent estimates indicate the additional force exerted upon the levees is equivalent to the square of the water level rise. Estimates using historical observations and climate model projections suggest that extreme high water levels in the Bay and Delta will increase markedly if sea level rises above its historical rate. These extremes are most likely to occur during storm events, leading to more severe damage from waves and floods.

Top left & right: Photos.com. Bottom: CA Fuel Cell Partnership

Cleaner energy and vehicle technologies can help California reduce global warming emissions, improve air quality, and protect public health.

Managing Global Warming

Continued global warming will have widespread and significant impacts on the Golden State. Solutions are available today to reduce emissions and minimize these impacts.

The projections presented in this analysis suggest that many of the most severe consequences that are expected from the medium and higher warming ranges could be avoided if heat-trapping emissions can be reduced to levels that will hold temperature increases at or below the lower warming range (i.e., an increase of no more than 5.5°F). However, even if emissions are substantially reduced, research indicates that some climatic changes are unavoidable. Although not the solution to global warming, plans to cope with these changes are essential.

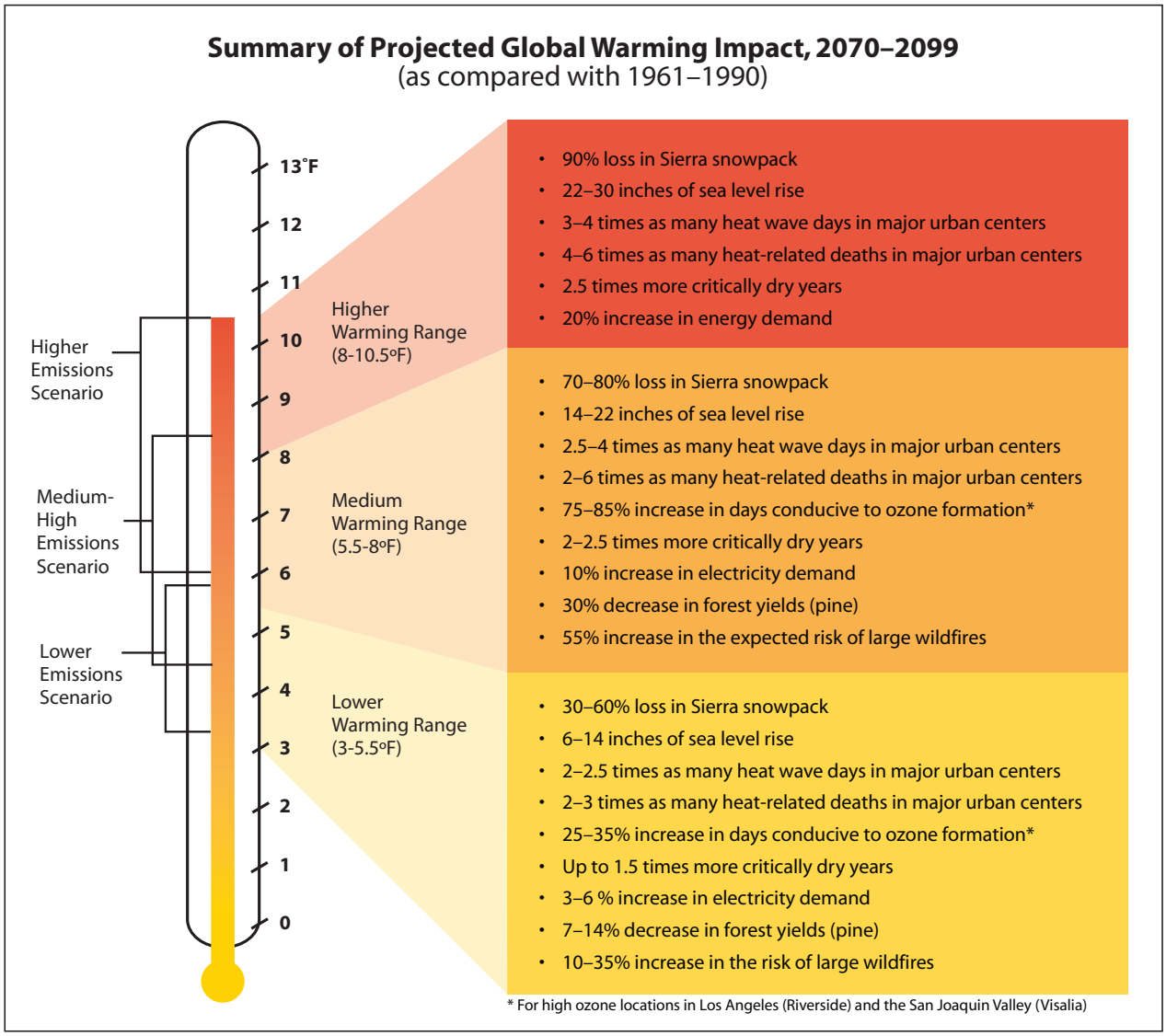
California's actions can drive global progress to address global warming.

Reducing Heat-Trapping Emissions

Reducing heat-trapping emissions is the most important way to slow the rate of global warming. On June 1, 2005, Governor Arnold Schwarzenegger signed an executive order (#S-3-05) that sets goals for significantly lowering the state's share of global warming pollution. The executive order calls for a reduction in heat-trapping emissions to 1990 levels by 2020 and for an 80 percent emissions reduction below 1990 levels by 2050. These emission reduction targets will help stimulate technological innovation needed to help transition to more efficient and renewable transportation and energy systems.

Coping with Unavoidable Climatic Changes

Because global warming is already upon us, and some amount of additional warming is inevitable, we must prepare for the changes that are already under way.



Preparing for these unavoidable changes will require minimizing further stresses on sensitive ecosystems and implementing management practices that integrate climate risks into long-term planning strategies.

California's Leadership

California has been a leader in both the science of climate change and in identifying solutions. The California Climate Change Center is one of the first—and perhaps the only—state-sponsored research institution in the nation dedicated to climate change research, and other state agencies such as the Air Resources Board support similar research. Continuing this strong research agenda is critical for developing effective strategies for addressing global warming in California.

The state has also been at the forefront of efforts to reduce heat-trapping emissions, passing precedent-setting policies such as aggressive standards for tailpipe emissions, renewable energy, and energy efficiency. However, existing policies are not likely to be sufficient to meet the ambitious emission reduction goals set by the governor. To meet these ambitious goals California will need to build on its legacy of environmental leadership and develop new strategies and technologies to reduce emissions.

By reducing heat-trapping emissions, severe consequences can be avoided.

California alone cannot stabilize the climate. However, the state's actions can drive global progress. If the industrialized world were to follow the emission reduction targets established in California's executive order, and industrializing nations reduced emissions according to the lower emissions path (B1) presented in this analysis, we would be on track to keep temperatures from rising to the medium or higher (and possibly even the lower) warming ranges and thus avoid the most severe consequences of global warming.

The full text of the Climate Scenarios analysis overview report, and the core scientific papers that comprise this analysis, are online at *www.climatechange.ca.gov*. The scientists that participated in this effort are:

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Net Ecosystem Exchanges of Carbon, Water, and Energy in Young and Old-growth Douglas-Fir Forests

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Abstract

To be able to estimate the cumulative carbon budget at broader scales, it is essential to understand net ecosystem exchanges (NEE) of carbon and water in various ages and types of ecosystems. Using eddy-covariance (EC) in Douglas-fir dominated forests in the Wind River Valley, Washington, USA, we measured NEE of carbon, water, and energy from July through September in a 40-year-old stand (40YR) in 1998, a 20-year-old stand (20YR) in 1999, and a 450-year-old stand (450YR) during both years. All three stands were net carbon sinks during the dry, warm summers, with mean net daily accumulation of -0.30 g C m^{-2} d^{-1}, -2.76 g C m^{-2} d^{-1}, and -0.38 g C m^{-2} d^{-1}, respectively, in the 20YR, 40YR, and 450YR (average of 1998, 1999) stands; but for individual years, the 450YR stand was a carbon source in 1998 (0.51 g C m^{-2} d^{-1}) and a sink in 1999 (-1.26 g C m^{-2} d^{-1}). The interannual differences for the summer months were apparent for cumulative carbon exchange at the 450YR stand, which had 46.9 g C m^{-2} loss in 1998 and 115.9 g C m^{-2} gain in 1999. As predicted, the 40YR stand assimilated the most carbon and lost the least amount of water to the atmosphere through evapotranspiration.

Key words: net ecosystem exchange; carbon; water; energy; Douglas-fir; eddy-covariance; microclimate.

Introduction

In recent years, as scientific interest in determining the roles of ecosystems as carbon sinks or sources has intensified, direct measurements of net ecosystem exchange (NEE) of carbon and water between terrestrial vegetation and the atmosphere have increased (for example, see Falge and others 2002). For forested regions, it is essential to understand the carbon fluxes of various-aged stands so that we can assess the impact of climate change and alternative land uses at landscape and regional scales (Turner and others 2000; Carey and others 2001). In terms of the major forces that drive changes in ecosystem productivity (Hansen and others 1991; Walker and Steffen 1997), there is a consensus among scientists that anthropogenic disturbances,—primarily land-use changes,—could have synergetic or even more severe impacts than climate change (Chen and others 1999; Dale and others 2002). In the western United States, for example, intensive human-induced land-use changes have led to the conversion of most of the virgin old-growth forests into younger stands, with consequent effects on the car-

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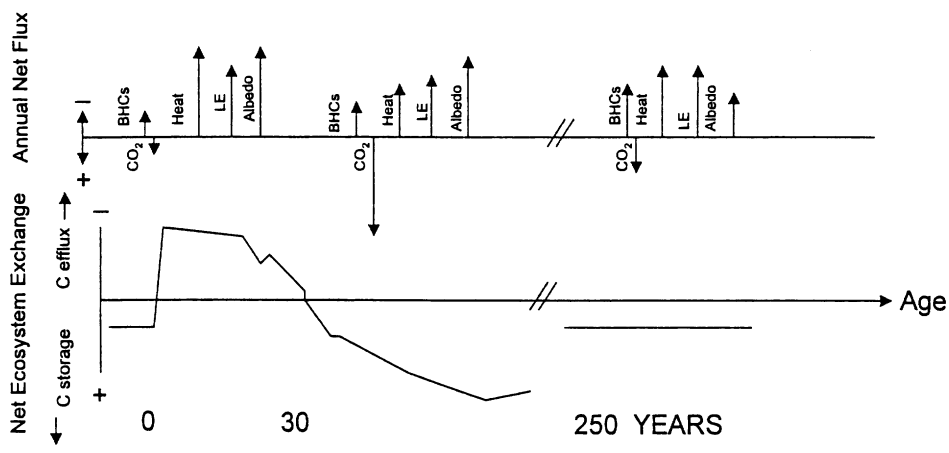

Figure 1. Upper panel: Hypothetical annual fluxes of biogenic hydrocarbons (BHCs), carbon dioxide (CO_2), sensible heat (H), latent heat (LE), and albedo for 20-year-old and 40-year-old stand and forests older than 250 years. Lower panel: Hypothetical net ecosystem exchange after a stand-replacing event.

bon fluxes and storage of the region (Harmon and others 1990). Indeed, Schimel and others (2000) have estimated that the effects of land conversion on carbon sequestration by US forests might be double that caused by the predicted global warming.

It has been hypothesized that terrestrial ecosystems in North America are sinks for atmospheric carbon (Tans and others 1990; Fan and others 1998); these systems could account for the missing carbon within the global carbon budget (Turner and others 1995), especially because many of them are young reforested stands. However, due to natural variability in carbon pools, fluxes in different terrestrial ecosystems (Sarmiento and Wofsy 1999), and problems with the precision and accuracy of measurements (Lee 1998) much uncertainty still exists in determining the location of the missing carbon sinks. Thus, it is becoming increasingly important to quantify NEE accurately at the broad spatial scales within which the contributions of individual ecosystems are understood. Currently, much of the available data are based on measurements at eddy flux towers, such as those obtained through the AmeriFlux and EuroFlux Networks, which are snapshots of larger land mosaics. Similarly, over longer temporal scales, it is well known that climatic variability (Wofsy and others 1993) and various disturbances (Dale and others 2002; Euskirchen and others 2002) drive the magnitudes and dynamics of carbon and water flux; however, drivers over shorter temporal periods are not as well understood. The work presented in this paper is one of the first attempts to quantify carbon flux at fine temporal scales within individual ecosystems of different ages within a landscape. Several projects within the CarboEurope Cluster program of the European Union have also been developed to address similar space/time scale questions (http://www.bgc.jena.mpg.de/public/carboeur/).

Our study objective was to compare the NEE of carbon and water in the summer season (July–September) among different-aged stands of Douglas-fir dominated forests. Franklin and others (2002) proposed that Douglas-fir/western hemlock forests at approximately 20–30 years should reach canopy closure and initiate the stage of rapid biomass accumulation, whereas mature forests (over 300 years old) should increase vertical and horizontal diversification due to mortality of the canopy dominants. When Janisch and Harmon (2002) modeled net ecosystem production (NEP) for these forests, they found that young stands shift from being a carbon source to a sink between 0 and 57 years. Thus, the transition between a forest acting as a source or a sink occurs near the 20–30-year period.

Figure 1 illustrates the hypothetical net annual ecosystem fluxes for energy budgets and carbon for forests of different ages. We chose to study 20-, 40-, and 450-year-old stands based on these probable functional transitions. The summer study period was selected based on the timing of onset of seasonal drought and the fact that drought has a major impact on the annual carbon budget (see Chen and others 2002; Unsworth and others 2004; Paw U and others 2004). The precipitation regime in the US Pacific Northwest is strongly seasonal, with little precipitation in summer months (Shaw and others 2004; Paw U and others 2004). The 3-month period between 1 July and 1 October encompasses the seasonal transition from high to low carbon sequestration (Waring and Franklin 1979; Paw U and others 2004).

We developed and installed mobile eddy-covariance (EC) systems in two Douglas-fir (*Pseudotsuga*

Table 1. Monthly Air Temperature (°C) between June and October of 1998 and 1999 at the Wind River Canopy Crane Research Facility

	1998				1999			
	Mean	Max	Min	SD	Mean	Max	Min	SD
June	14.81	30.73	5.06	5.19	13.85	31.95	1.86	5.51
July	19.97	39.70	7.98	6.21	16.61	33.18	3.52	6.81
August	19.07	36.60	5.20	7.19	18.64	33.90	7.72	6.10
September	15.86	36.37	2.28	7.24	14.91	28.71	3.03	7.03

menziesii) stands (20- and 40-year-old, abbreviated as 20YR and 40YR hereafter) to directly measure net exchange of carbon, water, and energy between the forest and the atmosphere and thereby test the hypothesis that both the 20-year-old stand and the 40-year-old stand should be near the zero-net exchange point for carbon and that the highest net flux would occur in the 40-year-old stand. Data collected from a more permanent EC system in a 450-year-old stand (450YR hereafter) (see Paw U and others 2004) were used for comparison. Specifically, we (a) compared carbon, water, and energy fluxes at hourly, daily, and monthly scales; and (b) examined possible biophysical controls of carbon and water fluxes along Douglas-fir chronosequences to assess the potential implications for forest management.

Methods

Our measurements were made at the Wind River Canopy Crane Research Facility (WRCCRF) in the T. T. Munger Research Natural Area and in the Trout Creek Hill Experimental Forest in the Gifford Pinchot National Forest, located in southwestern Washington, USA. (see Shaw and others 2004; Paw U and others 2004). The prevailing wind was from 270°, as determined by measurements between 1995 and 1998 at 70-m height on the canopy crane. The long-term average precipitation at the Wind River site is 2,467 mm y^{-1}, with only 5% occurring in June, July, and August (Paw U and others 2004; Shaw and others 2004). The summer of 1998 was extremely dry, as indicated by persistent drought until late September and record low soil moisture levels and high vapor pressure deficits (Unsworth and others 2004). Climate records show that these months were in the lowest quartile of monthly precipitation for the period from 1931 to 1997. In contrast, May 1999 was in the highest quartile for monthly precipitation, and June and July 1999 were near the long-term mean. The measured summer temperatures were significantly higher in the summer of 1998 than 1999 (Table 1).

Scaffolding towers for the younger tree canopies were constructed in spring 1998 near the east end of each stand to maximize the fetch of 30 tree heights in directions between 200° and 310°. The 36-m tower was placed in the 40YR stand in June 1998 and moved to the 20YR stand in June 1999.

The 20YR stand is located at 565 m a.s.l. It was clear-cut in 1976 and planted in 1978 with Douglas-fir seedlings at 2.7 m × 2.7 m spacing as part of a plantation experiment. The 33-ha stand was located 3.5 km west of the WRCCRF crane and was dominated in 1999 by Douglas-fir and western hemlock (*Tsuga heterophylla*) at a density of 1,529 trees ha^{-1}. Average tree height was 16 m, and average diameter at breast height (dbh) was 11.3 cm (Table 2). A 19.5-m scaffolding tower was installed with micrometeorological sensors at about 18.5 m above the ground.

The 40YR stand is located at 561 m a.s.l. It was clear-cut in 1958 and planted in 1960 with 3-year-old Douglas-fir at 1.8 m × 1.8 m spacing. The 33-ha stand was located about 6 km west of the WRCCRF and dominated by Douglas-fir (67.8%), with a mean density of 710 trees ha^{-1}. Average tree height was 31 m, with a closed canopy and a dbh of 19.3 cm (Table 2). A 36-m scaffolding tower was installed with micrometeorological sensors at about 36.2 m above the ground. The stand is located in the southwestern part of the Trout Creek Hill Experimental Forest on the residual lava flow.

The 450YR stand surrounds the canopy crane and is located within the T. T. Munger Research Natural Area. The Wind River Experimental forest is located at 371 m a.s.l. and is 4,208 ha in extent. The forest, which was approximately 450–550 years old, originated after a fire or a series of fires and continues to be dominated by Douglas-fir, although the stand is undergoing natural succession and is being gradu-

Table 2. Stand Structure and Site Information for Three Douglas-Fir Forests of Different Ages (20-year-old, 40-year-old, and old-growth 450-year-old) Used for Measurements of Microclimate and Fluxes of Carbon, Water, and Energy Obtained Using Eddy-Covariance Methods

	20YR	40YR	450YR
Latitude (°)	45°49'23.64"N	45°49'13.76"N	45°49'13.8"N
Longitude (°)	122°1'34.85"W	122°57'6.88"W	121°49'6.9"W
Elevation (m)	565	561	371
Age (y)	21	40	450
Last known disturbance (y)	1977	1959	500–600 bp
Stand density (tree ha^{-1})	1529	710	443
Mean tree height (m) ± SD	15.1 ± 1.77	31.4 ± 1.047	62 ± 12.5
Average dbh (cm)	11.3	19.3	33.8
Basal area (m^2)	19.30	44.77	71.93
LAI	6.8	8.6	8.9
Sampling period	7/15/99–10/15/99	6/18/98–1/15/98	5/98–10/99

dbh, diameter at breast height; LAI, leaf area index; bp, before present

ally replaced by western hemlock, western red cedar (*Thuja plicata*), Pacific silver fir (*Abies amabilis*), grand fir (*A. grandis*), noble fir (*A. procera*), and western white pine (*Pinus monticola*). It contains a tree density of 443 trees ha^{-1} and an aboveground biomass of 669 Mg ha^{-1}; it has an average height of 62 m, a dbh of 33.8 cm, and a basal area of 71.93 m^2 (Table 2). A 75-m construction tower was installed with micrometeorological sensors at about 70 m above the ground.

Tree heights in the 20YR and 40YR stands were measured on the tallest 20 trees using Ishii's equation (2000). All trees in the 12 ha around the WRC-CRF were measured; the mean heights of the tallest trees in the 4 ha immediately surrounding the crane are shown in Table 2.

Beginning in mid-June of their respective sampling years, measurements were taken in the young stands. Limited equipment and personnel prevented continuous measurements at all three sites simultaneously. A 3-D sonic anemometer (CSAT3; Campbell Scientific Instruments, Logan, UT, USA) was mounted in the 20YR and 40YR stands at 18.5 m and 36.0 m, respectively, facing 265° and 255°, toward the good fetch directions. A data logger (CR23X; Campbell Scientific Instruments) was programmed to measure sonic temperature and 10-Hz wind speeds in three orthogonal directions (that is, x, y, z). An infrared gas analyzer (Li-Cor 6262 IRGA; Li-Cor, Lincoln, NE, USA) was used to measure carbon dioxide (CO_2), water (H_2O), temperature, and chamber pressure at the same frequency. Heated Li-Cor Bev-A-Line tubing (4–5 m long) was used to draw ambient air at about 10 L min^{-1}. The IRGA was calibrated prior to installation and brought back to the laboratory every 2–3 weeks during the sampling period for recalibration and cross-calibration using the same gas and dew point generators as for the old-growth stand (Paw U and others 2004). Because of equipment and power supply limitations, we did not measure the canopy storage and advective terms at the young stands (Lee 1998; Paw U and others 2000). A net radiometer (Q7.1; Radiation Energy and Balance Systems, Seattle, WA, USA) was mounted more than 2 m above the canopy, and three soil heat flux plates (HFT3; Radiation Energy and Balance Systems) were buried near the soil surface (1 cm) to record continuous 30-min means of net radiation (R_n) and soil heat flux (G) based on 20-s scans. The instrumentation and measurements at the 450YR stand are described by Paw U and others (2004).

Results

Clear diurnal patterns in CO_2 exchanges (F_{CO2}) were observed (Figures 2 and 3), with CO_2 uptake (that is, C sink) dominating daylight hours and respiration (C source) dominating the night. Complex temporal patterns in F_{CO2} seemed to occur among the 3 sampling months and between the 2 sampling years. For example, the F_{CO2} of the old-growth forest in 1998 and 1999 was clearly different in both its average diurnal change (Figures 2 and 3) and daily cumulative values (Table 3). The 450YR stand was a net source in both July and September of 1998 (Table 3), but whereas high nocturnal respiration rates contributed to this in July, low daytime CO_2 uptakes were more significant in September (Figure 3). In addition, in 1998,

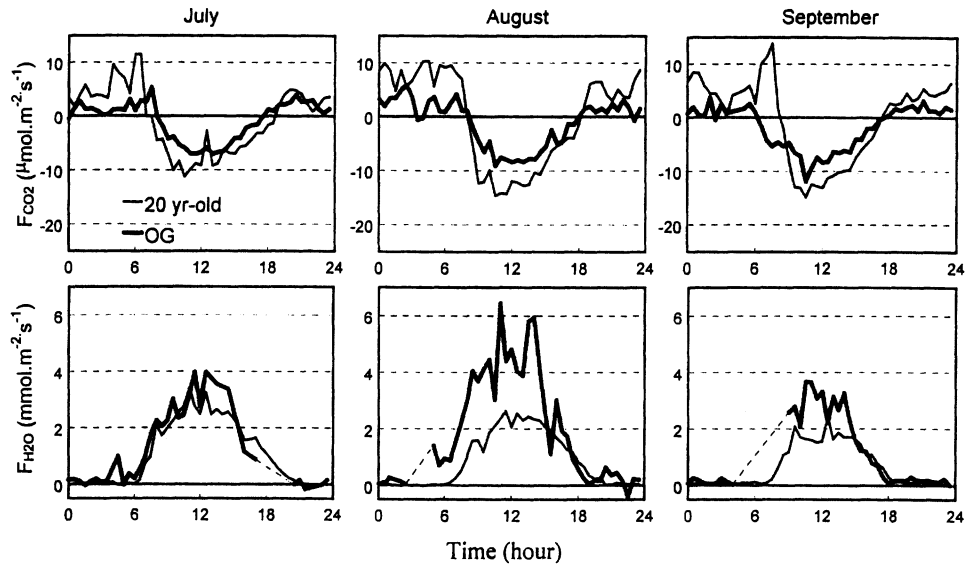

Figure 2. Average diurnal fluxes of carbon dioxide (CO_2) and water (H_2O) in July, August, and September 1999 in a 20- and a 450-year-old Douglas-fir forest in southern Washington, USA. Only data from good fetch directions (200–310°) were used. Negative values indicate uptake (that is, sink); positive values indicate loss (that is, source). Dashed lines indicate missing values.

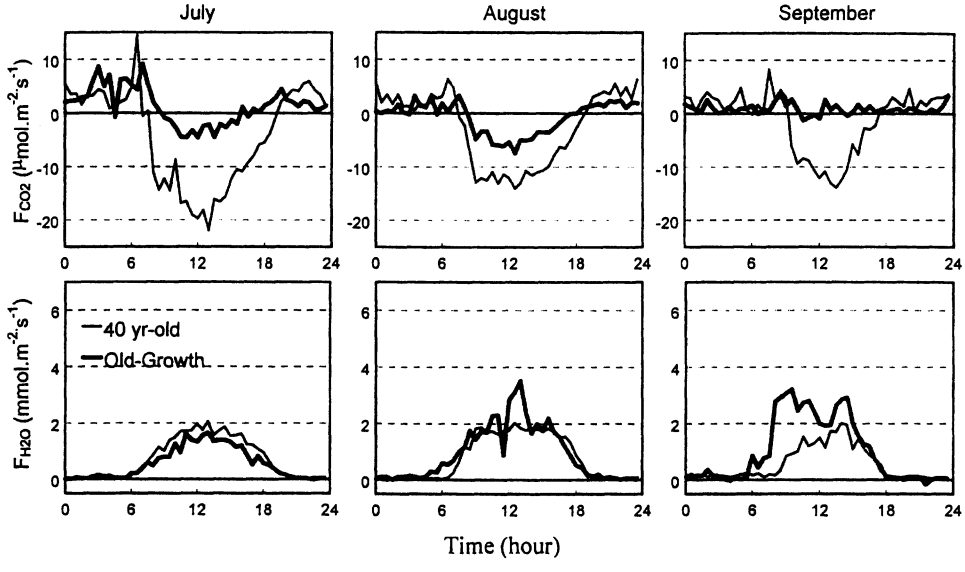

Figure 3. Average diurnal fluxes of carbon dioxide (CO_2) and water (H_2O) in July, August, and September 1998 in a 40- and a 450-year-old Douglas-fir forest in southern Washington, USA. Only data from good fetch directions (200–310°) were used. Negative values indicate uptake (that is, sink); positive values indicate loss (that is, source).

the 450YR stand lost an average of 0.51 g C m^{-2} d^{-1} (or 46.92 g C m^{-2} over the 3-month sampling period) to the atmosphere, but in 1999 it assimilated 1.26 g C m^{-2} d^{-1} (or 115.92 g C m^{-2} in 3 months) from the atmosphere (Table 3).

At the younger stands, F_{CO2} was higher than at the old-growth stand during the night, with largest values at the 20YR stand (Figure 2). Although daytime F_{CO2} at both of the young stands was larger (that is, more negative values at the old-growth stand), very small differences in daytime F_{CO2} were found between the 20YR and the 450YR stands in July 1999. Because of the high respiratory loss, the daily average F_{CO2} of the 20YR stand in 1999 (−0.30 g C m^{-2} d^{-1}) was 23.8% that of the 450YR stand (−1.26 g C m^{-2} d^{-1}) (Table 3). In comparing F_{CO2} between the 40YR and the 450YR in 1998, we found that nighttime F_{CO2} was slightly higher at the 40YR stand, but daytime F_{CO2} was also much higher (up to −20 μmol m^{-2} s^{-1} in July) (Figure 3). Over the 3-month sampling period, the daily average F_{CO2} was −2.76 g C m^{-2} d^{-1} at the 40YR stand but +0.51 g C m^{-2} d^{-1} (that is, a carbon source) at the 450YR stand (Table 3). In summary, the two younger stands were net carbon sinks from July through September, but the old-growth stand appeared to be a source in summer 1998 and a sink in summer 1999 (Table 3).

The F_{CO2} of the three coniferous stands showed clear relationships with the biophysical environment, with photosynthetically active radiation (PAR) and vapor pressure deficit (VPD) as the most important variables. The F_{CO2}–PAR relationship—a typical sigmoid increase with elevated PAR—was

Table 3. Average Daily Net Exchange of Carbon and Water in July, August, and September of 1998 and 1999 at Three Douglas-Fir Forests of Different Ages (20, 40, and 450 years old) in Southern Washington, USA

		1998		1999	
		40YR	450YR	20YR	450YR
Carbon (g C m^{-2} d^{-1})	July	−4.27	1.39	−0.56	−0.79
August	−2.69	−0.79	−0.01	−1.10	
September	−1.21	0.93	−0.33	−1.97	
Overall	−2.76	0.51	−0.30	−1.26	
Water (mm d^{-1})	July	1.15	0.87	1.67	2.09
August	1.20	1.43	1.36	2.98	
September	0.87	1.58	1.02	1.74	
Overall	1.15	1.29	1.35	2.30	
CWFR (g kg^{-1}/mmol mol^{-1})	July	3.71/5.57	−1.59/−2.35	0.34/0.51	0.38/0.57
August	2.24/3.36	0.55/0.83	0.007/0.010	0.37/0.56	
September	1.39/2.09	−0.59/−0.89	0.32/0.48	1.13/1.70	
Overall	2.40/3.60	−0.40/−0.60	0.22/0.33	0.55/0.83	

CWFR, carbon dioxide–water vapor flux ratio.
For carbon, negative values indicate uptake (that is, sink), whereas positive values indicate loss (that is, source). For CWFR, negative values indicate a carbon source associated with water loss.

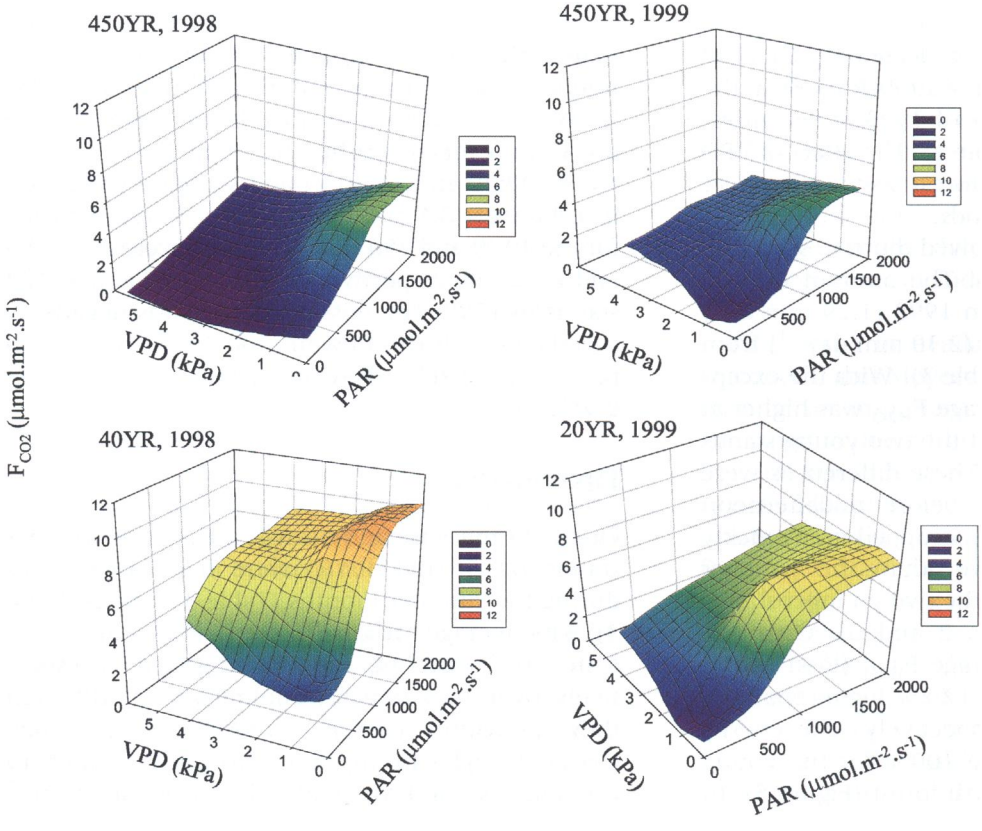

Figure 4. Effects of photosynthetically active radiation (PAR, µmol m^{-2} s^{-1}) and vapor pressure deficit (VDP, kPa) on mean carbon dioxide (CO_2) flux (F_{CO2}, µmol m^{-2} s^{-1}) during summer and fall (15 June and 15 October) in 1998 and 1999.

dependent of VPD at all three stands (Figure 4), with the 450YR in 1998 showing a clearly different response from the others. In the 450YR stand in 1999 and the two young stands, F_{CO2} decreased with increasing VPD at high PAR levels, but it increased at low PAR levels, suggesting stronger negative influences of VDP when photosynthesis reached high levels (that is, at high PAR) than that

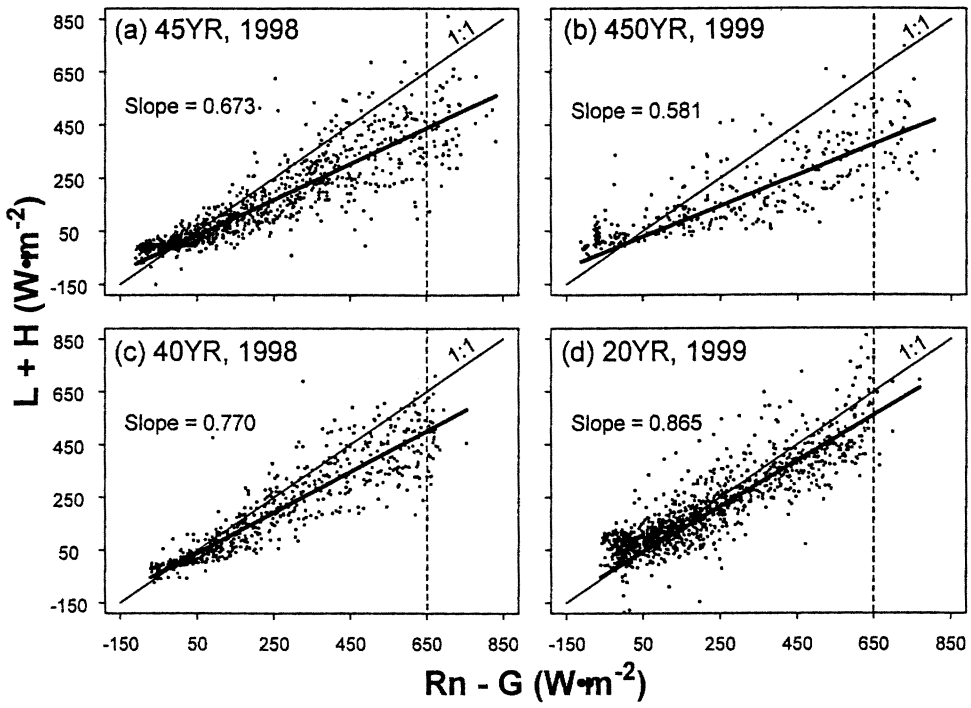

Figure 5. Energy budget closures of three stands as measured by 30-min means of net radiation (R_n), sensible heat (H), latent heat (L), and soil heat flux (G) between June and October in 1998 and 1999. Only data from good fetch directions (200–310°) were used.

at low PAR levels. However, a decreasing trend of F_{CO2} with VPD was observed at all PAR levels in the 450YR stand in the summer of 1998, when moisture was extremely low (Table 1). The effect of VPD on F_{CO2} at the old-growth forest seemed stronger than those at the young stands.

Water flux (F_{H2O}) also showed diurnal, seasonal, and interannual differences. The amount of H_2O lost from the 450YR stand in 1998 (1.29 mm d^{-1}) was much less than in 1999 (2.30 mm day^{-1}) from July through September (Table 3). With the exception of July 1998, daily average F_{H2O} was higher at the old-growth stand than at the two young stands (Figures 2 and 3, Table 3). These differences were associated with large F_{H2O} before midafternoon (around 14:00 h), when F_{H2O} dropped very quickly to levels similar to or lower than the younger stands. Decreases in F_{H2O} at the two younger stands were less dramatic (Figures 2 and 3). Over the sampling periods, daily average F_{H2O} (loss) of the 450YR stand was 70.4% and 12.2% higher than the 20YR and 40YR stands, respectively. The energy budget closure was closer to 100% for the young stands than for the old-growth forest (Figure 5). In 1998, the closure was 77% at the 40YR stand and 67% at the 450YR stand; whereas in 1999, the closure was 87% at the 20YR stand and 58% at the 450YR forest (Figure 5b and d). Nevertheless, on some days, energy budget closure was greater than 90% even in the old-growth stand. The available energy (R_n-G) in the old-growth stand seemed to be higher than in the younger stands, with values frequently greater than 650 W m^{-2} (Figure 5a and b). We found that the average Bowen ratios (based on 30-min mean sensible to latent heat ratio between 09:00 and 16:00 h) and standard deviations in 1998 were 3.7 ± 4.1 and 2.6 ± 2.7, respectively, for the 40YR and 450YR stands; they were 2.9 ± 2.9 and 1.6 ± 1.8, respectively, for the 20YR and 450YR stands in 1999. The missing energy was negatively correlated with the Bowen ratio (r^2 = −0.95) and positively correlated with canopy height (r^2 = 0.94).

Discussion

Our field measurements suggest that the younger stands (20YR and 40YR) were net carbon sinks during the summer months (Table 3, Figures 2 and 3), with average carbon fluxes of −0.30 and −2.76 g C m^{-2} d^{-1}, or 27.60 and 253.92 g C m^{-2}, respectively, over the 3-month sampling period. Although they are within the ranges reported for a young, coastal Douglas-fir forest in British Columbia (5 μmol m^{-2} s^{-1} at PAR greater than 1,000 μmol m^{-2} s^{-1}) (Wilson and others 2002), they are much smaller than values reported for other temperate forests during the growing season (Black and others 1996; Greco and Baldochhi 1996; Wofsy and others 1993; Wilson and others 2002). The values are higher than those reported in boreal coniferous forests (Hollinger and others 1998; Law and others

2001) and lower than those in tropical and southern deciduous forests (Greco and Baldocchi 1996; Clark and others 1999) and a Mediterranean beech forest in Italy (Valentini and others 1996).

Surprisingly, the 450YR stand was a carbon source in 1998 (0.51 g C m^{-2} d^{-1}, or 46.9 g C m^{-2} total for the study period), but it was a significant sink for the same period in 1999 (−1.26 g C m^{-2} d^{-1}, or 115.9 g C m^{-2} total). These values constitute about 24.6% of the loss and 61.0% of the annual net carbon accumulation between July 1998 and June 1999 of the total net 1.9 ± 0.2 Mg C ha^{-1} measured in the 450 YR forest (Paw U and others 2004). Thus, the role of the old-growth stand as either source or sink appears to be markedly dependent on the local climate conditions (Wofsy and others 1993; Paw U and others 2004).

Because the study area is characterized by a warm, dry summer climate, photosynthetic uptake in this period is typically limited by moisture (Waring and Running 1998). The 1998 year was an unusually dry summer with almost no measurable precipitation, compared with an average precipitation (around 120 mm) during the same period in 1999; this may explain why there was a carbon loss in the old-growth forest in 1998 and a carbon gain in 1999.

Waring and Franklin (1979) hypothesized that a large proportion of ecosystem productivity occurs during winter and spring in these evergreen forests, when net photosynthetic gain is combined with low respiration. Our eddy flux measurements at the old-growth stand confirm that summer carbon assimilation is lower than maximum rates recorded in March (Paw U and others 2004), but that net assimilation can continue into late summer during years with more spring precipitation. Clearly, continuous direct measurements of carbon flux are needed (especially for young stands) during winter and spring to quantify the annual carbon budget and to gain a fuller understanding of the controls on carbon flux.

The 24-h water-use efficiency, as indicated by using the carbon dioxide–water vapor flux ratio (CWFR), was higher for the 40YR stand (2.4 g kg^{-1}) than the 450YR stand (−0.40 g kg^{-1}) in the summer of 1998, but the 450YR stand had a higher CWFR (0.55 g kg^{-1}) than the 20YR stand (0.22 g kg^{-1}) in the summer of 1999 (Table 3). It is generally thought that the CWFR increases when the stomatal or surface resistance increases (Rosenberg and others 1983), at least for individual leaves and daytime CWFR. Our results are therefore consistent with the sap flow–derived resistances and direct gas exchange measurements (McDowell and others 2002) for these forests, which were higher for the 40YR stand than the 450YR stand in 1999 and higher for the 450YR stand than the 20YR stand in 1998 and 1999 (Phillips and others 2002). Our results also support the leaf/branch level gas exchange measurements of Thomas and Winner (2000) for this 450YR stand and a 5–10-year-old stand, which found higher CWFR for the 450YR stand, if it is inferred that the CWFR for the 5–10-year-old stand is similar to that of the 20YR. Isotopic studies also imply a higher stomatal or surface resistance for the 450YR stand than younger stands (Fessenden and Ehleringer 2002), which supports our CWFR estimates for the 1999 data but not the 1998 data. However, isotopic data for plant tissue and other carbon stocks are subject to multiple interpretations because several factors may create isotopic ratio variations (Bowling and others 2003).

The marked difference of CWFR for the 450YR stand between years implies that there is a potential for great interannual variation between summers. In 1998, the negative value of CWFR indicated a carbon source while water was still being lost from the ecosystem; whereas in 1999, the CWFR was not only positive but greater than CWRF in a younger ecosystem. One caution that must be noted in comparing the 24-h CWFR and the CWFR derived from daytime-based measurements and measurements on particular plant elements is that nocturnal respiration and other element respiration (including soil, large woody debris, and understory carbon exchange) are included in the EC-based 24-h CWFR.

Differences in available energy (that is, R_n-G) (Baldocchi and Meyers 1991) among the three sites may be an important factor for the higher F_{H2O} measured at the old-growth site. For example, Eugster and others (1997) found that F_{H2O} was linearly correlated with R_n across landscapes. In our study, it was common for the old-growth forest to reach R_n greater than 650 W m^{-2} (Figure 5a and b) but rare for R_n at the either younger stands to reach these levels (Figure 5c and d), suggesting that F_{H2O} should be higher at the older stand to maintain leaf temperatures. The old-growth forest has exceptionally low albedo (Mariscal and others 2004) in contrast to younger stands (Roberts and others 2004), which explains the higher net radiation at this site. The lack of energy budget closure at the old-growth forest for both years (Figure 5 a and b) additionally suggests that we probably underestimated F_{H2O}, proportional to the difference in net energy at the sites, that was likely underestimated in the calculation of F_{H2O}.

The contribution of understory vegetation offers

yet another potential explanation for the relatively high F_{H2O} at the old-growth site. Abundant understory vegetation typically contributes 5%–10% of total ecosystem F_{H2O} (Price and others 1986), but this may increase significantly when stands are patchy or open, or when soils are dry. For example, Tan and others (1978) found that the percentage of total ecosystem transpiration accounted for by the understory (salal) of a thinned Douglas-fir stand increased from 45% to 70% over a 4-week drying period. In our study, there was almost no understory at either younger stands, whereas it was abundant in the old-growth stand, suggesting that classical water-use efficiency theory may need to be adjusted when applied at the ecosystem level.

Our results for F_{H2O} are similar to those observed in a ponderosa pine (*Pinus ponderosa*) forest in the eastern Cascades of Oregon (Law and others 2001; Irvine and others 2002), where both F_{H2O} and F_{CO2} were lower in young stands than in older ones. However, in the pine ecosystems, there was evidence that the old-growth trees were able to access deeper sources of water than the younger trees (Irvine and others 2002). Ongoing studies of root distribution and water uptake with depth at the Wind River sites have shown no indication that roots in the old-growth stand had access to water at depths unavailable to younger stands (B. J. Bond and others unpublished; Brooks and others 2002), although total fine-root biomass was significantly greater in the old stand than the two younger stands (Klopatek 2002). Despite the greater overall F_{H2O} at the old-growth stand compared with the younger stands, differences in the diurnal behavior of F_{H2O} at the three stands indicated that there was greater midday stomatal regulation of transpiration in the old stand (Yoder and others 1994).

Conclusions

One of the most significant findings of this study concerns the large variation in NEE of CO_2, H_2O, and energy among differently aged forest stands of the same type within the same landscape that results from differences in species composition, tree age and structure, microclimates, soils, and disturbance regimes (Chen and others 1999). This suggests that flux measurements obtained at single locations are not representative of the overall landscape, thus limiting the applicability of these results at broader spatial scales. More work is needed to understand the scaling mechanisms in complex forest landscapes. If EC systems are used to establish a regional carbon budget, it is clear that they must be established at multiple sites across the landscape instead of taking measurements only at a single point, or they must be placed at sufficient heights to measure flux footprints that include other landscape types (although horizontal advection below the sensors must then be addressed). Finally, serious attention should be given to developing a more complete understanding of the coupled effects of climate change and land use on terrestrial ecosystems.

Caution should be used in interpreting our findings that indicate higher carbon sequestration in young stands than in old-growth stands, because our results strongly suggest that the old-growth forest may be a stronger carbon sink than previously believed. However, given its shift between a carbon source and sink in these two summers, the potential for long-term net carbon accumulation in the old-growth stand is uncertain. The 2 years of data for the summer season examined imply that these forests are sensitive to interannual weather conditions and thus will be sensitive to any directional climate change.

The conversion of long-lived forests into young stands may change the system from a sink to a source of carbon for several decades because the lower leaf area in regenerating forests limits photosynthesis while the residual carbon in soils and woody debris contributes to respiration, whereas old-growth forests may continue to function as a net carbon sink, in addition to their many other important ecosystem functions (for example, critical habitat, aesthetic values, watershed protection). Stands younger than 20 years old are expected to be carbon sources because of low photosynthetic potential and substantial respiratory losses (Janisch and Harmon 2002), but no such stands were examined in this study. Our sites are not perfect chronological sequences due to many physical and ecological differences—for example, elevation, soil nutrients, climate, and historical silvicultural treatments (Chen and others 2002; Klopatek 2002)—but this study does demonstrate the importance of age structure in determining the carbon budget. Further investigation of carbon and water fluxes in multiple ecosystems along chronological stages of development are needed because we know very little about the mechanisms or timing that switch forest ecosystems from carbon sources to sinks following a disturbance.

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REFERENCES

Baldocchi DD, Meyers TP. 1991. Trace gas exchange above the floor of a deciduous forest. 1. Evaporation and CO_2 efflux. J Geophys Res 96:7271–85.

Black TA, Denhartog G, Neumann HH, Blanken PD, Yang PC, Russel G, Nesic Z, and others. 1996. Annual cycles of water vapour and carbon dioxide fluxes in and above a boreal aspen forest. Global Change Biol 2:219–29.

Bowling DR, Pataki DE, Ehleringer JR. 2003. Critical evaluation of micrometeorological methods for measuring ecosystem–atmosphere isotopic exchange of CO_2. Agric For Meteorol 116:159–79.

Brooks JR, Meiner FC, Coulombe R, Gregg J. 2002. Hydraulic redistribution of soil water during summer drought in two contrasting Pacific Northwest coniferous forests. Tree Physiol 22:1107–17.

Carey EV, Sala A, Kean R, Callaway RM. 2001. Are old-forests underestimated as carbon sinks. Global Change Biol 7:339–44.

Chen J, Saunders S, Crow T, Naiman R, Brosofske K, Mroz G, Brookshire B, and others. 1999. Microclimate in forest ecosystem and landscape ecology. BioScience 49:288–97.

Chen J, Falk M, Paw U KT, Suchanek T, Ustin S, Bond B, Brosofske K, and others. 2002. Biophysical controls of carbon flows in three successional Douglas-fir stands based upon eddy-covariance measurements. Tree Physiol 22:171–80.

Clark KL, Gholz HL, Moncrieff JB, Cropley F, Loescher HW. 1999. Environmental controls over net exchanges of carbon dioxide from contrasting Florida ecosystems. Ecol Appl 9:936–48.

Dale VH, Joyce LA, McNulty S, Neilson RR, Ayres MP, Flannigan MD, Hanson PJ, and others. 2002. Climate change and forest disturbances. BioScience 51(9):723–34.

Eugster W, McFadden JP, Chapin FS III. 1997. A comparative approach to regional variation in surface fluxes using mobile eddy correlation towers. Boundary-Layer Meteorol 85:293–307.

Euskirchen E, Chen J, Li H, Gustafson EJ, Crow TR. 2002. Modeling net carbon flows under alternative management regimes at a landscape level. Ecol Model 154:75–91.

Falge E, Tenhunen J, Baldocchi D, Aubinet M, Bakwin P, Berbigier P, Bernhofer C, and others. 2002. Phase and amplitude of ecosystem carbon release and uptake potentials as derived from FLUXNET measurements. Agric For Meteorol 113:75–95.

Fan S, Gloor M, Mahlman J, Pacala S, Sarmiento J, Takahashi T, Tans P. 1998. A large terrestrial carbon sink in North America implied by atmospheric and oceanic carbon dioxide data and models. Science 282:442–6.

Fessenden JE, Ehleringer JR. 2002. Age-related variations in $d^{13}C$ of ecosystem respiration across a coniferous forest chronosequence in the Pacific Northwest. Tree Physiol 22:159–67.

Franklin JF, Spies TA, Van Pelt R, Carey AB, Thornburgh DA, Berg DR, Lindenmayer DB, and others. 2002. Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. For Ecol Manage 155:399–423.

Greco S, Baldocchi DD. 1996. Seasonal variation of CO_2 and water vapour exchange rates over a temperate deciduous forest. Global Change Biol 2:183–97.

Hansen AJ, Spies TA, Swanson FJ, Ohmann JL. 1991. Conserving biodiversity in managed forests: lessons from natural forests. BioScience 41:382–92.

Harmon ME, Ferrell WK, Franklin JF. 1990. Effects on carbon storage of conversion of old-growth forests to young forests. Science 247:699–702.

Hollinger DY, Kelliher FM, Schulze E-D, Bauer G, Arneth A, Byers JN, Hunt JE, and others. 1998. Forest–atmosphere carbon dioxide exchange in eastern Siberia. Agric For Meteorol 90:291–306.

Irvine J, Law BE, Anthoni PM, Meinzer FC. 2002. Water limitations to carbon exchange in old-growth and young ponderosa pine stands. Tree Physiol 22:189–96.

Ishii H, Reynolds JH, Ford ED, Shaw DC. 2000. Height growth and vertical development of an old-growth Pseudotsuga-Tsuga forest in southwestern Washington State, U.S.A. Can J For Res 30:17–24.

Janisch E, Harmon ME. 2002. Successional changes in live and dead wood carbon stores: implications for net ecosystem productivity. Tree Physiol 22:77–89.

Klopatek JM. 2002. Belowground carbon pools and processes in different age stands of Douglas-fir. Tree Physiol 22:197–204.

Law BE, Thornton PE, Irvine J, Anthoni PM, Van Tuyl S. 2001. Carbon storage and fluxes in ponderosa pine forests at different developmental stages. Global Change Biol 7:755–77.

Lee X. 1998. On micrometeorological observation of surface–air exchange over tall vegetation. Agric For Meteorol 91:39–45.

Marisical MJ, Martens SN, Chen, J, Roberts D, Ustin SL (2004) "Spatial variability of PAR within canopy gaps in an old-growth Douglas-fir/western hemlock forest". Ecosystems 7: 454–67.

McDowell N, Phillips N, Lunch C, Bond BJ, Ryan MG. 2002. An investigation of hydraulic limitation and compensation in large, old Douglas-fir trees. Tree Physiol 22:763–74.

Paw U KT, Baldocchi DD, Meyers TP, Wilson KB. 2000. Correction of eddy-covariance measurements incorporating both advective effects and density fluxes. Boundary-Layer Meteorol 97:487–511.

Paw U KT, Suchanek TH, Ustin SL, Chen J, Park Y-S, Winner W, and others. (2004) Carbon dioxide exchange between an old-growth forest and the atmosphere. Ecosystems 7:513–24.

Phillips N, Bond BJ, McDowell NG, Ryan MG. 2002. Canopy and hydraulic conductance in young, mature and old Douglas-fir trees. Tree Physiol 22:205–11.

Price DT, Black TA, Kelliher FM. 1986. Effects of salal understory

removal on photosynthetic rate and stomatal conductance in young Douglas-fir trees. Can J For Res 16:90–7.

Roberts DA, Ustin SL, Ogunjemiyo S, Chen J, Hinkley TM. 2004. Spectral and structural measures of Northwest forest vegetation at leaf to landscape scales. Ecosystems 7:545–62.

Rosenberg NJ, Blad BL, Verma SB. 1983, Microclimate: the biological environment. New York: Wiley.

Sarmiento JL, Wofsy SC. (1999) A U.S. carbon cycle science plan. Report of the Carbon and Climate Working Group, Washington D.C.

Schimel DJ, Melillo J, Tian H, McGuire AD, Kicklighter D, Kittel T, Rosenbloom N, and others. 2000. The contribution of increasing CO_2 and climate to carbon storage by natural and agricultural ecosystems of the US 1980–1993. Science 287: 2004–6.

Shaw DC, Franklin JF, Bible K, Klopatek J, Freeman E, Greene S, Parker GG (2004) "Ecological setting of the Wind River old-growth forest". Ecosystems 7:427–39.

Tan CS, Black TA, Nnyamah JU. 1978. A simple diffusion model of transpiration applied to a thinned Douglas-fir stand. Ecology 59(6):1221–9.

Tans PP, Fung IY, Takahashi T. 1990. Observational constraints on the global atmospheric CO_2 budget. Science 247:1431–8.

Thomas SC, Winner WE. 2000. Leaf area index of an old-growth Douglas-fir forest estimated from direct structural measurements. Can J For Res 30:1922–30.

Turner DP, Koerper GJ, Harmon ME, Lee JJ. 1995. A carbon budget for forests of the conterminous United States. Ecol Appl 5:421–36.

Turner DP, Cohen WB, Kennedy RE. 2000. Alternative spatial resolutions and estimation of carbon flux over a managed forest landscape in western Oregon. Landscape Ecol 15(5): 441–52.

Unsworth MH, Phillips N, Link T, Bond B, Falk M, Harmon M, Hinckley T, and others. 2004. Components and controls of water flux in an old-growth Douglas-fir/western hemlock ecosystem. Ecosystems (7:)468–81.

Valentini R, De Angelis P, Matteucci G, Monaco R, Dore S, Mugnozza GES. 1996. Seasonal net carbon dioxide exchange of a beech forest with the atmosphere. Global Change Biol 2:199–207.

Walker B, Steffen W. 1997. An overview of the implications of global change for natural and managed terrestrial ecosystems. Conserv Ecol. Available online at http://www.consecol.org/vol1/iss2/art2.

Waring R, Franklin JF. 1979. Evergreen coniferous forests of the Pacific Northwest. Science 204:1380–6.

Waring R, Running SW. 1998, Forest ecosystems: analysis at multiple scales. San Diego: Academic Press.

Wilson K, Goldstein AH, Falge E, Aubinet M, Baldocchi D, Aubinet M, Berbigier P, and others. 2002. Energy balance closure at FLUXNET sites. Agric For Meteorol 113:223–43.

Wofsy SC, Goulden ML, Munger JW, Fan S-M, Bakwin PS, Daube BC, Bassow SL, and others. 1993. Net exchange of CO_2 in a mid-latitude forest. Science 260:1314–7.

Yoder BJ, Ryan MG, Waring RH, Schoettle AW, Kaufmann MR. 1994. Evidence of reduced photosynthesis rates in old trees. For Sci 40(3):513–27.

The Resource Agency's 2010 Guideline Update

Greenhouse Gas Emissions:
SB 97 and Things to Consider

SB 97, 2007 Dutton (Public Resource Code 21083.05)

(a) On or before July 1, 2009, the Office of Planning and Research shall prepare, develop, and transmit to the Resources Agency guidelines for <u>the mitigation of greenhouse gas emissions or the effects of greenhouse gas emissions</u> as required by this division, including, but not limited to, <u>effects associated with transportation or energy consumption</u>.

(b) On or before January 1, 2010, the Resources Agency shall certify and adopt guidelines prepared and developed by the Office of Planning and Research pursuant to subdivision (a).

(c) The Office of Planning and Research and the Resources Agency shall periodically update the guidelines to incorporate new information or criteria established by the State Air Resources Board pursuant to Division 25.5 (commencing with Section 38500) of the Health and Safety Code.

Resources' Goals

- Two Public Workshops Jointly with OPR in January
- Gather Any Substantial Evidence Needed to Submit to Rulemaking
- Notice of Rulemaking Package Submitted and Processed
- Official Public Comment Period
- Submit Final Package/Adopt and Certify

Overview

- General Obligation to Analyze GHG emissions
- Methodologies- Gathering of Evidence and Defensibility of a Good Record
- Thresholds of Significance
- Mitigation

You Must Analyze Impacts from GHG

- AG's Approach Has Been to Draft Letters Regarding GHG
- *California v. San Bernardino County*, April 2007- comprehensive land use planning update failed to quantify and mitigate GHG emissions. Settled with requirement to quantify and mitigate.
- OPR issued a technical advisory on this issue in 2007
- SB 97 Passed in 2007
- OPR's unofficial draft was released on January 10, 2009

You Must Analyze Impacts from GHG Cont.

- Prior to 2007, Courts Were Struggling with this Issue
- Courts that Did not Require Analysis (Caution: Pre-Regulation of this Issue):
  - *American Canyon Community United for Responsible Growth et al. v. City of American Canyon et al.* –(Napa County Superior Court, May 22, 2007; no appeal pending). The court upheld the city's determination that AB 32's passage did not trigger new information requiring a supplemental EIR for a Walmart Supercenter.
  - *Natural Resources Defense Council et al. v. Reclamation Board of the Resources Agency of the State of California* (ghg analysis "unknown" at the time of fill/encroachment permits issued for Delta)
  - *Highland Springs v. City of Banning*, Case No. RIC460950 (January 29, 2008) ruled that CEQA did not require the city to consider the GHG impacts of a project to develop 1,453 housing units with a school site and other amenities since "no law required the Banning City Council to consider global warming at the time it approved [the] project."

You Must Analyze Impacts from GHG Cont.

- Courts Have and Will Now Require Analysis.
- Courts that Have Required Are:
  - *Center for Biological Diversity v. City of Desert Hot Springs*, Case No. RIC464585 (August 6, 2008; no appeal pending), the court held that the city violated CEQA by failing to consider the ghg emissions from a luxury resort (Riverside)
  - *Environmental Council of Sacramento v. California Department of Transportation*, Case No. 07CS00967 (July 15, 2008; no appeal pending), California Department of Transportation (Cal Trans) – GHG emissions for new occupancy lane were required because project proceeded the limited exemption in SB 97 for transportation projects. (Sacramento)
  - *Westfield v. City of Arcadia*, Case No. BS108923 (July 23, 2008; no appeal pending) – Analysis of ghg was sufficient (LA)
  - *Natural Resources Defense Council, Inc. v. South Coast Air Quality Management District – Rulemaking for SCAQMD required analysis and quantification of ghg (LA)*

You Must Analyze Impacts from GHG Cont.

- Outside of California, a number of jurisdictions, including the State of Massachusetts and Washington, now require a GHG analysis in environmental analyses submitted under their environmental review statutes

Making a Defensible Record- Substantial Evidence

- Determinations About GHG Impacts and Their Significance Must be Supported by Substantial Evidence.
- What Constitutes Substantial Evidence: Facts, reasonable assumptions based on facts, exert opinions supported by facts, relevant personal observations where such observations not require technical expertise (See, 14 Cal. Code Regs. Section 15384; *Pocket Protectors v. City of Sacramento* (2004) 124 Cal.App.4th 903, 928.)
- What Does Not Constitute Substantial Evidence: argument, speculation, unsubstantiated opinion or narrative, evidence that is clearly inaccurate or erroneous, or evidence of economic or social impacts that do not contribute to or are not caused b physical environmental impacts.

Applying Substantial Evidence to Record Preparation

- The “substantial evidence test” applies to all factual determinations made by a lead agency.
- “Substantial Evidence” means enough relevant information and reasonable inferences from this information that a fair argument can be made to support a conclusion, even though other conclusions might also be reached.

Making a Defensible Record

- What Areas Should Be Considered
  - Type of Forest Management (Clear Cutting or other types of logging management)
  - Age of forest at issue, tree type
  - Store of Carbon in Bio Mass, Soil, and Old Growth
  - Rate new growth sequesters carbon
  - Changes to system overall
  - Reduction of carbon stores v. rate of carbon uptake
  - Increases and Decreases in Carbon to Environmental Setting
  - Cumulative Impacts
- How do you Calculate Emissions
  - Direct and Indirect
  - Short and Long Term
- Offsets, Net Gains
- What Emissions Should be Included
  - Lifecycle
  - AG: “reasonably known sources” to avoid speculation and double counting
  - Direct/Indirect Impacts are Regulatory Standard (No Speculation)

Determining Significance

- Thresholds of Significance will be the BIG issue.
- How Much Carbon Release is Significant/How much loss of Carbon Storage is Significant?
- Again, Substantial Evidence Required:
  - **The threshold of significance for a given environmental effect is simply that level at which the Lead Agency finds the effects of the project to be significant. (OPR, *Thresholds of Significance: Criteria for Defining Environmental Significance* [CEQA technical advisory series, 1994.] [Circular- Consider the tipping point of an impact on the environment]**
  - **A threshold of significance is an identifiable quantitative, qualitative, or performance level of a particular environmental effect, noncompliance with which means the effect will normally be determined to be significance by the agency and compliance with which means the effect normally will be determined to be less than significant. (14 Cal. Code Regs. 15064.7)**

Standards of Review To Keep In Mind

- A lead agency's factual determinations are given "substantial deference" and are presumed correct; the challenger bears the burden of proving the contrary. (Thresholds themselves)

- Fair Argument: A lead agency must require an EIR (or its equivalent- THP) where it is presented with substantial evidence supporting a fair argument that significant environmental impacts <u>may</u> result from a project, even though there is also substantial evidence in the record to the contrary. (Application of Thresholds to facts).

Regulatory Standards/Recommendations/Targets

- Targets passed during regulatory process for AB 32 do not constitute thresholds of significance absent substantial evidence in the lead agency's record
- Recommendations regarding thresholds do not constitute thresholds absent substantial evidence in the lead agency's record
- *Communities for a Better Environment v. Resources Agency* (2002) 103 Cal. App. 4th 98 [Presumption that compliance with regulatory standards makes a project "less than significant" was overturned because this presumption could interfere with the "fair argument" standard.]
- Bottom Line: Discretion to use regulatory standards not eviscerated, but not presumed, now agencies must support all thresholds with substantial evidence.

Possible Avenues for Approach

- Analysis of Greenhouse Gas Emissions is No Longer Considered “Too Speculative”
- Cumulative Problem/Where to Establish Baseline
- Net Zero Approach
- Business As Usual/a.k.a.- Baseline approach and Currently degraded state (*Kings County Farm Bureau v. City of Hanford* (1990) 221 Cal.Aoo.3d 692, 721.)
  - Floating Baselines
  - Traditional Regional Approaches v. Global Nature of Problem
- CARB/OPR Approach
  - Programmatic EIRs/Updated Plans
  - Performance Based Standards
  - Numeric Thresholds supported by Substantial Evidence

Further Considerations

- Feasible Mitigation Concepts
  - Offsets (on/off site)
  - Net Benefits
  - Project Level Mitigation
    - Best Technology
    - Construction Practices
  - Adoption of BMPs
  - Sequestration
- Statement of Overriding Considerations NOT impacted
  - Substantial evidence that public benefits of the project outweigh significant impacts that cannot be substantially lessened or mitigated. (14 Cal. Code Regs. Sec 15043)

Credits

- A Review of Climate Change Decisions in California Trial Courts, Chelsea Holloway of Holland and Knight, LLP. September 29, 2008: http://www.eli.org/pdf/alerts/Holland_Knight_09-29-08.pdf
- Article: CEQA Rules For Agency Actions Affecting Climate Change, Environmental Law Reporter (Nov. 2008, Vol. 11), Barry H. Epstein, Paul S. Kibel and Sara N. Pasquinelli

GIS in Rangeland Management

Vineyard Expansion in Sonoma County: Mapping, monitoring, and changing policies

Prepared by Adina Merenlender and Colin Brooks
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Project Summary

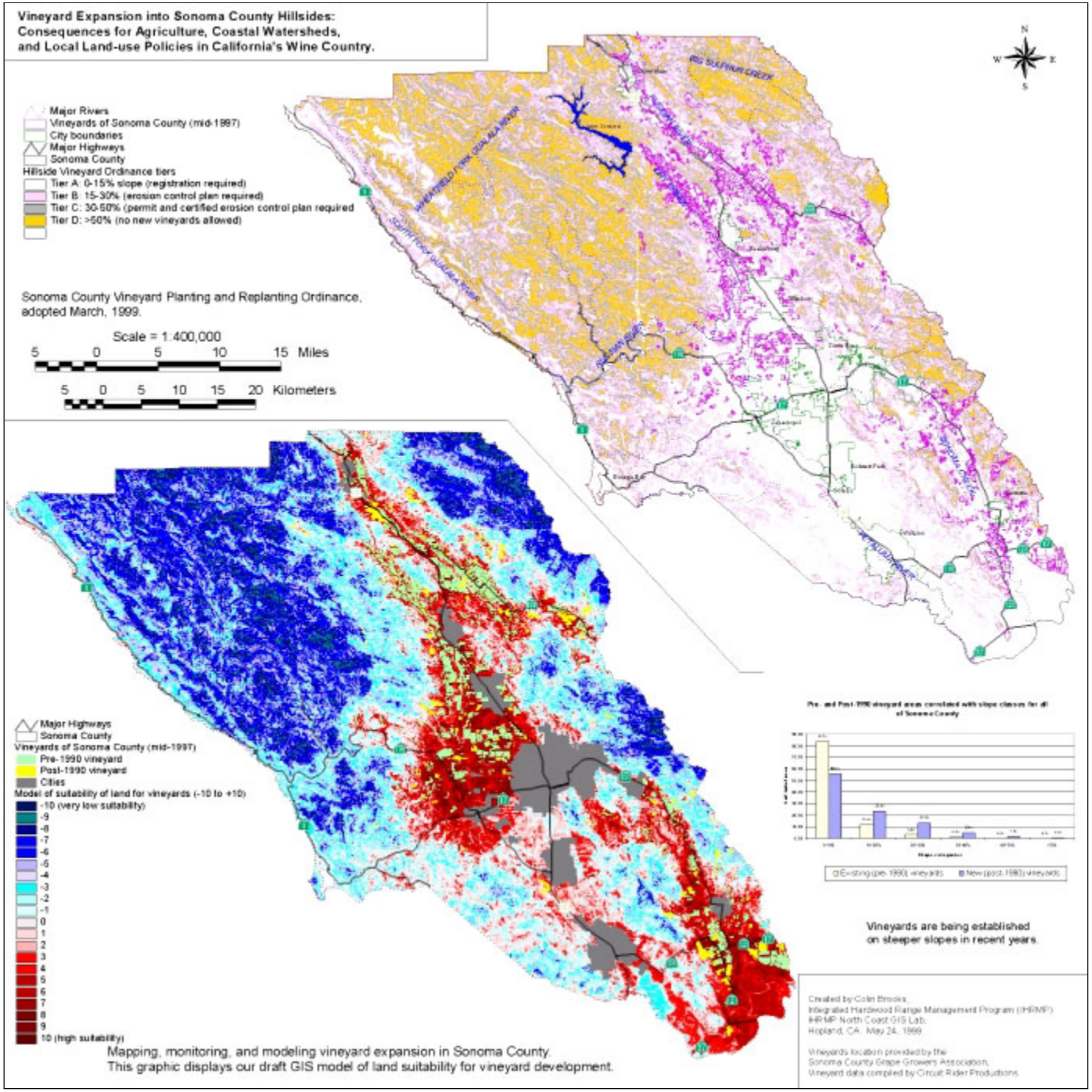
California wines have become extremely popular nationally and internationally, leading to increased demand for wine grapes. Upland areas, historically considered marginal agricultural land, are increasingly targeted for vineyard development. In some areas, the conversion from woodlands and forestland to vineyard is extensive. For example, Santa Barbara County Planning Department reported that the amount of vineyard has doubled to 20,000 acres since 1996 leading to the loss of over 2,000 oak trees, a larger number than all rural development and subdivisions were responsible for removing in the past ten years. Most recently, a 10,000 acre vineyard is being proposed in what is now currently coastal redwood forest lands - the largest single conversion of its kind. Understandably, vineyard owners are coming under increasing scrutiny from urban neighbors, the environmental community, and government agencies concerned about the effect of vineyards on natural resources. For example, riparian vegetation clearing, wetland conversion, endangered species, hillside erosion, native tree removal, and impeded wildlife migration corridors have become contentious issues facing vineyardists in California.

In response to citizens concerns, local regulatory policies are rapidly evolving to prevent hillside erosion and protect natural resources. In particular, Sonoma County recently instigated hillside agricultural development restrictions to prevent soil loss and protect stream corridors. This local ordinance requires farmers to register new vineyards and represents some of the first restrictions to agricultural development in California.

The results from this research project currently provides an assessment of where vineyards are in Sonoma County and addresses the related natural resource issues and local policies that are associated with hillside agricultural expansion. The vineyards mapped in these figures are in the major wine grape growing regions of Sonoma County. Using this data we calculated that approximately 12,000 acres of new vineyards were planted from 1990 through 1997. This makes a total of at least 48,000 acres in 1997, 20% more than were reported in the 1998 County Crop Report. From this data we were also able to measure the extent to which recent vineyard development has moved to steeper hillsides (see chart). In fact, 25% of the vineyards developed since 1990 were on slopes greater than 10 degrees and 42% are above 100 meters in elevation. For comparison, less than 6% of the vineyards established prior to 1990 were on slopes greater than 10 degrees and only 18% were above 100 meters.

In order to evaluate the consequences of proposed and enacted local regulations on agriculture and the environment we mapped the areas in Sonoma County that will have different permitting responsibilities depending on slope due to the recently adopted Sonoma County Vineyard Planting and Replanting Ordinance (upper map). We are currently using spatially explicit models to identify areas that may be more suitable for vineyard development based on recent trends in vineyard expansion (lower map). The pattern of vineyard development is influenced by physiographic, environmental, and land-use variables.

In summary, are examining changes in oak woodland connectivity, effects of changing environmental policies, and areas of land-use conflict are examined to strive for sustainable agriculture on a landscape scale.


Vineyard Expansion into Sonoma County Hillsides:
Consequences for Agriculture, Coastal Watersheds,
and Local Land-use Policies in California's Wine Country.
Major Rivers
Vineyards of Sonoma County (mid-1997)
City boundaries
Major Highways
Sonoma County
Hillside Vineyard Ordinance tiers
Tier A: 0-15% slope (registration required)
Tier B: 15-30% (erosion control plan required)
Tier C: 30-50% (permit and certified erosion control plan required
Tier D: >50% (no new vineyards allowed)
Sonoma County Vineyard Planting and Replanting Ordinance,
adopted March, 1999.
Scale = 1:400,000
5 0 5 10 15 Miles
5 0 5 10 15 20 Kilometers
Major Highways
Sonoma County
Vineyards of Sonoma County (mid-1997)
Pre-1990 vineyard
Post-1990 vineyard
Cities
Model of suitability of land for vineyards (-10 to +10)
-10 (very low suitability)
10 (high suitability)
Mapping, monitoring, and modeling vineyard expansion in Sonoma County.
This graphic displays our draft GIS model of land suitability for vineyard development.
Vineyards are being established
on steeper slopes in recent years.
Created by Colin Brooks,
Integrated Hardwood Range Management Program (IHRMP)
IHRMP North Coast GIS Lab,
Hopland, CA. May 24, 1999.
Vineyards location provided by the
Sonoma County Grape Growers Association.
Vineyard data compiled by Circuit Rider Productions.

Prepared May 1999.

Technical Advisory

CEQA AND CLIMATE CHANGE: Addressing Climate Change Through California Environmental Quality Act (CEQA) Review

This technical advisory is one in a series of advisories provided by the Governor's Office of Planning and Research (OPR) as a service to professional planners, land use officials and CEQA practitioners. OPR issues technical guidance from time to time on issues that broadly affect the practice of CEQA and land use planning. The emerging role of CEQA in addressing climate change and greenhouse gas emissions has been the topic of much discussion and debate in recent months. This document provides OPR's perspective on the issue.

I. PURPOSE

General scientific consensus and increasing public awareness regarding global warming and climate change have placed new focus on the California Environmental Quality Act (CEQA) review process as a means to address the effects of greenhouse gas (GHG) emissions from proposed projects on climate change. Many public agencies—along with academic, business, and community organizations—are striving to determine the appropriate means by which to evaluate and mitigate the impacts of proposed projects on climate change. Approaches and methodologies for calculating GHG emissions and addressing the environmental impacts through CEQA review are rapidly evolving and are increasingly available to assist public agencies to prepare their CEQA documents and make informed decisions.

JUNE 19, 2008

STATE OF CALIFORNIA
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The Governor's Office of Planning and Research (OPR) will develop, and the California Resources Agency (Resources Agency) will certify and adopt amendments to the Guidelines implementing the California Environmental Quality Act ("CEQA Guidelines"), on or before January 1, 2010, pursuant to Senate Bill 97 (Dutton, 2007). These new CEQA Guidelines will provide regulatory guidance on the analysis and mitigation of GHG emissions in CEQA documents. In the interim, OPR offers the following informal guidance regarding the steps lead agencies should take to address climate change in their CEQA documents. This guidance was developed in cooperation with the Resources Agency, the California Environmental Protection Agency (Cal/EPA), and the California Air Resources Board (ARB).

II. BACKGROUND

Climate change refers to any significant change in measures of climate, such as average temperature, precipitation, or wind patterns over a period of time. Climate change may result from natural factors, natural processes, and human activities that change the composition of the atmosphere and alter the surface and features of the land. Significant changes in global climate patterns have recently been associated with global warming, an average increase in the temperature of the atmosphere near the Earth's surface, attributed to accumulation of GHG emissions in the atmosphere. Greenhouse gases trap heat in the atmosphere, which in turn heats the surface of the Earth. Some GHGs occur naturally and are emitted to the atmosphere through natural processes, while others are created and emitted solely through human activities. The emission of GHGs through the combustion of fossil fuels (i.e., fuels containing carbon) in conjunction with other human activities, appears to be closely associated with global warming.

State law defines GHG to include the following: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride (Health and Safety Code, section 38505(g).) The most common GHG that results from human activity is carbon dioxide, followed by methane and nitrous oxide.

Requirements of AB 32 and SB 97

Assembly Bill 32 (AB 32), the California Global Warming Solutions Act of 2006 (Nunez, 2006), recognizes that California is the source of substantial amounts of GHG emissions. The statute begins with several legislative findings and declarations of intent, including the following:

> Global warming poses a serious threat to the economic well-being, public health, natural resources, and the environment of California. The potential adverse impacts of global warming include the exacerbation of air quality problems, a reduction in the quality and supply of water to the state from the Sierra snow pack, a rise in sea levels resulting in the displacement of thousands of coastal businesses and residences, damage to marine ecosystems and the natural environment, and an increase in the incidences of infectious diseases, asthma, and other human health-related problems. (Health and Safety Code, section 38501.)

In order to avert these consequences, AB 32 establishes a state goal of reducing GHG emissions to 1990 levels by the year 2020 (a reduction of approximately 25 percent from forecast emission levels) with further reductions to follow. The law requires the ARB to establish a program to track and report GHG emissions; approve a scoping plan for achieving the maximum technologically feasible and cost effective reductions from sources of GHG emissions; adopt early reduction measures to begin moving forward; and adopt, implement and enforce regulations – including market mechanisms such as "cap-and-trade" programs – to ensure the required reductions occur. The ARB recently adopted a statewide GHG emissions limit and an emissions inventory, along with requirements to measure, track, and report GHG emissions by the industries it determined to be significant sources of GHG emissions.

CEQA requires public agencies to identify the potentially significant effects on the environment of projects they intend to carry out or approve, and to mitigate significant effects whenever it is feasible to do so. While AB 32 did not amend CEQA to require new analytic processes to account for the environmental impacts of GHG emissions from projects subject to CEQA, it does acknowledge that such emissions cause significant adverse impacts to human health and the environment.

Senate Bill 97, enacted in 2007, amends the CEQA statute to clearly establish that GHG emissions and the effects of GHG emissions are appropriate subjects for CEQA analysis. It directs OPR to develop draft CEQA Guidelines "for the mitigation of greenhouse gas emissions or the effects of greenhouse gas emissions" by July 1, 2009 and directs the Resources Agency to certify and adopt the CEQA Guidelines by January 1, 2010.

Requirements of CEQA

CEQA is a public disclosure law that requires public agencies to make a

good-faith, reasoned effort, based upon available information, to identify the potentially significant direct and indirect environmental impacts—including cumulative impacts— of a proposed project or activity. The CEQA process is intended to inform the public of the potential environmental effects of proposed government decisions and to encourage informed decision-making by public agencies. In addition, CEQA obligates public agencies to consider less environmentally-damaging alternatives and adopt feasible mitigation measures to reduce or avoid a project's significant impacts.

The lead agency is required to prepare an Environmental Impact Report (EIR), a Mitigated Negative Declaration, or equivalent document, when it determines that the project's impacts on the environment are potentially significant. This determination of significance must be based upon substantial evidence in light of all the information before the agency.

Although the CEQA Guidelines, at Appendix G, provide a checklist of suggested issues that should be addressed in an EIR, neither the CEQA statute nor the CEQA Guidelines prescribe thresholds of significance or particular methodologies for performing an impact analysis. This is left to lead agency judgment and discretion, based upon factual data and guidance from regulatory agencies and other sources where available and applicable. A threshold of significance is essentially a regulatory standard or set of criteria that represent the level at which a lead agency finds a particular environmental effect of a project to be significant. Compliance with a given threshold means the effect normally will be considered less than significant. Public agencies are encouraged but not required to adopt thresholds of significance for environmental impacts. Even in the absence of clearly defined thresholds for GHG emissions, the law requires that such emissions from CEQA projects must be disclosed and mitigated to the extent feasible whenever the lead agency determines that the project contributes to a significant, cumulative climate change impact.

We realize that perhaps the most difficult part of the climate change analysis will be the determination of significance. Although lead agencies typically rely on local or regional definitions of significance for most environmental issues, the global nature of climate change warrants investigation of a statewide threshold of significance for GHG emissions. To this end, OPR has asked ARB technical staff to recommend a method for setting thresholds which will encourage consistency and uniformity in the CEQA analysis of GHG emissions throughout the state. Until such time as state guidance is available on thresholds of significance for GHG emissions, we recommend the following approach to your CEQA analysis.

III. RECOMMENDED APPROACH

Each public agency that is a lead agency for complying with CEQA needs to develop its own approach to performing a climate change analysis for projects that generate GHG emissions. A consistent approach should be applied for the analysis of all such projects, and the analysis must be based on best available information. For these projects, compliance with CEQA entails three basic steps: identify and quantify the GHG emissions; assess the significance of the impact on climate change; and if the impact is found to be significant, identify alternatives and/or mitigation measures that will reduce the impact below significance.

Lead agencies should determine whether greenhouse gases may be generated by a proposed project, and if so, quantify or estimate the GHG emissions by type and source. Second, the lead agency must assess whether those emissions are individually or cumulatively significant. When assessing whether a project's effects on climate change are "cumulatively considerable" even though its GHG contribution may be individually limited, the lead agency must consider the impact of the project when viewed in connection with the effects of past, current, and probable future projects. Finally, if the lead agency determines that the GHG emissions from the project as proposed are potentially significant, it must investigate and implement ways to avoid, reduce, or otherwise mitigate the impacts of those emissions. Although the scientific knowledge and understanding of how best to perform this analysis is rudimentary and still evolving, many useful resources are available (see Attachment 1).

Until such time as further state guidance is available on thresholds of significance, public agencies should consider the following general factors when analyzing whether a proposed project has the potential to cause a significant climate change impact on the environment.

Identify GHG Emissions

- Lead agencies should make a good-faith effort, based on available information, to calculate, model, or estimate the amount of CO_2 and other GHG emissions from a project, including the emissions associated with vehicular traffic, energy consumption, water usage and construction activities.
- Technical resources, including a variety of modeling tools, are available to assist public agencies to quantify GHG emissions. OPR recognizes that more sophisticated emissions models for particular types of projects are continually being developed and that the state-of-the-art quantification

models are rapidly changing. OPR will periodically update the examples of modeling tools identified in Attachment 2.

- There is no standard format for including the analysis in a CEQA document. A GHG/climate change analysis can be included in one or more of the typical sections of an EIR (e.g., air quality, transportation, energy) or may be provided in a separate section on cumulative impacts or climate change.

Determine Significance

- When assessing a project's GHG emissions, lead agencies must describe the existing environmental conditions or setting, without the project, which normally constitutes the baseline physical conditions for determining whether a project's impacts are significant.
- As with any environmental impact, lead agencies must determine what constitutes a significant impact. In the absence of regulatory standards for GHG emissions or other scientific data to clearly define what constitutes a "significant impact", individual lead agencies may undertake a project-by-project analysis, consistent with available guidance and current CEQA practice.
- The potential effects of a project may be individually limited but cumulatively considerable. Lead agencies should not dismiss a proposed project's direct and/or indirect climate change impacts without careful consideration, supported by substantial evidence. Documentation of available information and analysis should be provided for any project that may significantly contribute new GHG emissions, either individually or cumulatively, directly or indirectly (e.g., transportation impacts).
- Although climate change is ultimately a cumulative impact, not every individual project that emits GHGs must necessarily be found to contribute to a significant cumulative impact on the environment. CEQA authorizes reliance on previously approved plans and mitigation programs that have adequately analyzed and mitigated GHG emissions to a less than significant level as a means to avoid or substantially reduce the cumulative impact of a project.

Mitigate Impacts

- Mitigation measures will vary with the type of project being contemplated, but may include alternative project designs or locations that conserve energy and water, measures that reduce vehicle miles traveled

(VMT) by fossil-fueled vehicles, measures that contribute to established regional or programmatic mitigation strategies, and measures that sequester carbon to offset the emissions from the project.

- The lead agency must impose all mitigation measures that are necessary to reduce GHG emissions to a less than significant level. CEQA does not require mitigation measures that are infeasible for specific legal, economic, technological, or other reasons. A lead agency is not responsible for wholly eliminating all GHG emissions from a project; the CEQA standard is to mitigate to a level that is "less than significant".
- If there are not sufficient mitigation measures that the lead agency determines are feasible to achieve the less than significant level, the lead agency should adopt those measures that are feasible, and adopt a Statement of Overriding Considerations that explains why further mitigation is not feasible. A Statement of Overriding Considerations must be prepared when the lead agency has determined to approve a project for which certain impacts are unavoidable. These statements should explain the reasons why the impacts cannot be adequately mitigated in sufficient detail, and must be based on specific facts, so as not to be conclusory.
- Agencies are encouraged to develop standard GHG emission reduction or mitigation measures that can be applied on a project-by-project basis. Attachment 3 contains a preliminary menu of measures that lead agencies may wish to consider. This list is by no means exhaustive or prescriptive. Lead agencies are encouraged to develop their own measures and/or propose project alternatives to reduce GHG emissions, either at a programmatic level or on a case-by-case review.
- In some cases GHG emission reduction measures will not be feasible or may not be effective at a project level. Rather, it may be more appropriate and more effective to develop and adopt program-level plans, policies and measures that will result in a reduction of GHG emissions on a regional level.

IV. ADDITIONAL LAND USE CONSIDERATIONS

CEQA can be a more effective tool for GHG emissions analysis and mitigation if it is supported and supplemented by sound development policies and practices that will reduce GHG emissions on a broad planning scale and that can provide the basis for a programmatic approach to project-specific CEQA analysis and mitigation.

Local governments with land use authority are beginning to establish policies that result in land use patterns and practices that will result in less energy use and reduce GHG emissions. For example, some cities and counties have adopted general plans and policies that encourage the development of compact, mixed-use, transit-oriented development that reduces VMT; encourage alternative fuel vehicle use; conserve energy and water usage; and promote carbon sequestration. Models of such developments exist throughout the state (see OPR climate change website for examples of city and county plans and policies, referenced in Attachment 1).

For local government lead agencies, adoption of general plan policies and certification of general plan EIRs that analyze broad jurisdiction-wide impacts of GHG emissions can be part of an effective strategy for addressing cumulative impacts and for streamlining later project-specific CEQA reviews.

International, national, and statewide organizations such as ICLEI (Local Governments for Sustainability), the Cities for Climate Protection, and the Clean Cities Coalition —to name just a few — have published guidebooks to help local governments reduce GHG emissions through land use planning techniques and improved municipal operations. Links to these resources are provided at the end of this advisory.

Regional agencies can also employ a variety of strategies to reduce GHG emissions through their planning processes. For example, regional transportation planning agencies adopt plans and programs that address congestion relief, jobs-to-housing balance, reduction of vehicle miles traveled (VMT), and other issues that have implications for GHG emission reductions.

State agencies are also tackling the issue of climate change. Some have adopted or support policies and programs that take climate change into account, including the Department of Water Resources' State Water Plan; the Department of Transportation's State Transportation Plan; and the Business, Housing and Transportation Agency's Regional Blueprint Planning Program. These efforts not only raise public awareness of climate change and how the State can reduce GHG emissions, but also offer specific information and resources for lead agencies to consider.

V. NEXT STEPS

OPR has asked ARB technical staff to recommend a method for setting a threshold of significance for GHG emissions. OPR has requested that the ARB identify a range of feasible options, including qualitative and quantitative options.

OPR is actively seeking input from the public and stakeholder groups, as it develops draft CEQA Guidelines for GHG emissions. OPR is engaged with the Resources Agency and other expert state agencies, local governments, builders and developers, environmental organizations, and others with expertise or an interest in the development of the Guidelines.

OPR will conduct public workshops later this year to receive input on the scope and content of the CEQA Guidelines amendments. It is OPR's intent to release a preliminary draft of the CEQA Guidelines amendments for public review and comment in the fall. This will enable OPR to deliver a proposed package of CEQA Guidelines amendments to the Resources Agency as early as January 2009, well before the statutory due date of July 1, 2009.

We encourage public agencies and the public to refer to the OPR website at www.opr.ca.gov for information about the CEQA Guidelines development process and to subscribe to OPR's notification system for announcements and updates.

For more information about this technical advisory and assistance in addressing the impacts of GHG emissions on the environment, please contact:

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ATTACHMENTS

1. References and Information Sources
2. Technical Resources/Modeling Tools to Estimate GHG Emissions
3. Examples of GHG Reduction Measures

Attachment 1

References and Information Sources

The following is a list of websites of organizations that can offer additional information regarding methods to characterize, quantify, assess and reduce GHG emissions. In addition, a list of useful resources and reference materials is provided on the subject of climate change and greenhouse gases.

ORGANIZATIONS

- Governor's Office of Planning and Research
  http://www.opr.ca.gov
- California Climate Action Team
  http://www.climatechange.ca.gov/climate_action_team/
- California Climate Change Portal
  http://www.climatechange.ca.gov
- California Air Resources Board Climate Change Website
  http://www.arb.ca.gov/cc/cc.htm
- California Climate Action Registry
  http://www.climateregistry.org/
- California Department of Water Resources, Climate Change and California Water Plan Website
  http://www.waterplan.water.ca.gov/climate/
- California Energy Commission Climate Change Proceedings
  http://www.energy.ca.gov/global_climate_change/index.html
- California Public Utilities Commission, Climate Change Website
  http://www.cpuc.ca.gov/static/energy/electric/climate+change/_index.htm
- Green California Website
  http://www.green.ca.gov/default.htm
- Western Climate Initiative
  http://www.westernclimateinitiative.org

- California Air Pollution Control Officers Association
  http://www.capcoa.org
- Local Governments for Sustainability (ICLEI)
  http://www.iclei.org/
- ICLEI Cities for Climate Protection (CCP)
  http://www.iclei.org/index.php?id=800
- United Nations Framework Convention on Climate Change
  http://unfccc.int/2860.php
- Intergovernmental Panel on Climate Change
  http://www.ipcc.ch
- United States Environmental Protection Agency
  http://www.epa.gov/climatechange/
- City of Seattle U.S. Mayors Climate Protection Agreement
  http://www.seattle.gov/mayor/climate/
- Mayors for Climate Protection
  http://www..coolmayors.com
- U.S. Conference of Mayors Climate Protection Web Page
  http://usmayors.org/climateprotection
- Institute for Local Government California Climate Action Network
  http://www.ca-ilg.org/climatechange

STATUTES, REGULATIONS, AND EXECUTIVE ORDERS

- SB 97
  http://opr.ca.gov/ceqa/pdfs/SB_97_bill_20070824_chaptered.pdf
- SB 97 Governor's Signing Message
  http://opr.ca.gov/ceqa/pdfs/SB-97-signing-message.pdf
- AB 32
  http://www.leginfo.ca.gov/pub/05-06/bill/asm/ab_0001-0050/ab_32_bill_20060927_chaptered.pdf
- AB 1493
  http://www.leginfo.ca.gov/pub/01-02/bill/asm/ab_1451-1500/ab_1493_bill_20020722_chaptered.pdf

- Regulations implementing AB 1493

  http://www.arb.ca.gov/regact/grnhsgas/revfro.pdf and http://www.arb.ca.gov/regact/grnhsgas/revtp.pdf

- SB 1368

  http://www.leginfo.ca.gov/pub/05-06/bill/sen/sb_1351-1400/sb_1368_bill_20060929_chaptered.pdf

- Executive Order S-01-07 regarding low carbon standard for transportation fuels

  http://gov.ca.gov/index.php?/executive-order/5172/

- Executive Order S-20-06 regarding implementation of AB 32

  http://gov.ca.gov/index.php?/executive-order/4484/

- Executive Order S-3-05 regarding greenhouse gas goals

  http://gov.ca.gov/index.php?/executive-order/1861/

- Executive Order S-20-04 regarding energy conservation by state

  http://gov.ca.gov/index.php?/executive-order/3360/

REPORTS

- OPR List of Environmental Documents Addressing Climate Change

  http://opr.ca.gov/ceqa/pdfs/Environmental_Assessment_Climate_Change.pdf

- OPR List of Local Plans Addressing Climate Change

  http://opr.ca.gov/ceqa/pdfs/City_and_County_Plans_Addressing_Climate_Change.pdf

- *Climate Action Team Proposed Early Action Measures to Mitigate Climate Change in California*, April 2007

  http://www.climatechange.ca.gov/climate_action_team/reports/2007-04-20_CAT_REPORT.PDF

- California Air Resources Board, *Early Action Items to Mitigate Climate Change in California*, October 2007

  http://www.arb.ca.gov/cc/ccea/meetings/ea_final_report.pdf

- California Air Resourced Board, *Draft Greenhouse Gas Inventory*, November 2007

  http://www.arb.ca.gov/cc/inventory/data/tables/rpt_Inventory_IPCC_All_2007-11-19.pdf

- *Climate Action Team Report to the Governor and Legislature*, March 2006, http://www.climatechange.ca.gov/climate_action_team/reports/index.html

- California Climate Change Center, *Our Changing Planet: Assessing the Risks to California - Summary Report*

  http://www.energy.ca.gov/2006publications/CEC-500-2006-077/CEC-500-2006-077.PDF

  Detailed reports available at: http://www.climatechange.ca.gov/biennial_reports/2006report/index.html

- California Energy Commission, *2007 Integrated Energy Policy Report Update*

  http://www.energy.ca.gov/2007publications/CEC-100-2007-008/CEC-100-2007-008-CMF.PDF

- California Department of Water Resources, *Progress on Incorporating Climate Change into Management of California's Water Resources*

  http://baydeltaoffice.water.ca.gov/climatechange/DWRClimateChangeJuly06.pdf - pagemode=bookmarks&page=1

- *Climate Action Program at Caltrans*, December 2006

  http://www.dot.ca.gov/docs/ClimateReport.pdf

- California Air Pollution Control Officers Association, *CEQA & Climate Change,* January 2008

  http://www.capcoa.org/ceqa/CAPCOA%20White%20Paper%20-%20CEQA%20and%20Climate%20Change.pdf

- West Coast Governors' Global Warming Initiative, November 2004

  http://www.climatechange.ca.gov/westcoast/documents/2004-11_final_report/2004-11-18_STAFF_RECOMMENDS.PDF

- Western Climate Initiative Work Plan, October 2007

  http://www.westernclimateinitiative.org/ewebeditpro/items/O104F13792.pdf

- California Climate Change Center, University of California at Berkeley, *Managing Greenhouse Gas Emissions in California,* 2007

  http://calclimate.berkeley.edu/managing_GHGs_in_CA.html

- U.S. Conference of Mayors, *Energy & Environment Best Practices*

  http://www.usmayors.org/climateprotection/AtlantaEESummitCDROMVersion.pdf

- *U.S. Mayors Climate Protection Agreement Climate Action Handbook*, 2006

  http://www.seattle.gov/climate/docs/ClimateActionHandbook.pdf

- Natural Capitalism Solutions *Climate Protection Manual for Cities*, June 2007

  http://www.climatemanual.org

- National Governor's Association Center for Best Practices *Growing with Less Greenhouse Gases*, November 2002

  http://www.nga.org/cda/files/112002ghg.pdf

- National Governor's Association Center for Best Practices *State and Regional Greenhouse Gas* Initiatives, October 2006

  http://www.nga.org/Files/pdf/0610GREENHOUSE.PDF

- United States Climate Change Program *The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States*, May 2008

  http://www.usda.gov/oce/global_change/sap_2007_FinalReport.htm

Attachment 2

Technical Resources/Modeling Tools to Estimate GHG Emissions

TOOL	AVAILABILITY	SCOPE LOCAL/ REGIONAL	SCOPE TRANSPORTATION/ BUILDINGS	DATA INPUT REQUIREMENTS	DATA OUTPUT
URBEMIS	• Download • Public domain (free)	• Local project level	• Transportation • Some building (area source) outputs • Construction	• Land use information • Construction, area source, and transportation assumptions	• CO2 (pounds per day) • Mitigation impacts
Clean Air and Climate Protection (CACP) Software	• Download • Available to public agencies (free)	• Local project level	• Buildings • Communities • Governments	• Energy usage • Waste generation and disposal • Transportation fuel usage or VMT	• CO2e (tons per year)
Sustainable Communities Model (SCM)	• Custom model	• Regional • Scalable to site level	• Transportation • Buildings • Neighborhoods • Master planned communities	• Location and site specific information • Transportation assumptions • On-site energy usage	• CO2e (tons per year)
Internet-accessed Planning for Community Energy, Economic and Environmental Sustainability I-PLACE^{3}S	• Web-based • Small access fee • Full model now available in eight CA counties	• Regional • Scalable to site level	• Transportation • Housing • Land Use • Buildings • Energy • Economics	• Parcel level land use data (ability to work with less data) • Project-level data for alternative comparisons	• CO2 (any quantity over any time)
Climate Action Registry Reporting On-Line Tool (CARROT)	• Web-based • Available to Registry members • General public can view entity reports	• Regional, scalable to entity and facility level	• General Reporting and Certification Protocols o Transportation o Buildings/facilities • Specific protocols for some sectors	• Mobile source combustion (VMT or fuel usage) • Stationary combustion (fuel usage) • Indirect emissions (electricity usage)	• Each GHG and CO2e (tons per year)
EMFAC	• Download • Public domain (free)	• Statewide • Regional (air basin level)	• Transportation emission factors	• Travel activity data to calculate CO2 from projects.	• CO2 and methane (grams per mile) emission factors

VMT = Vehicle miles traveled
eCO2 = Carbon dioxide equivalent emissions
Note: This is not meant to be a definitive list of modeling tools to estimate climate change emissions impacts. Other tools may be available.

Description of Modeling Tools

URBEMIS

The Urban Emissions Model is used extensively during the CEQA process by local air districts and consultants to determine the impacts of projects on criteria pollutants. It was recently updated to calculate CO2 emissions as well. Future updates will include additional greenhouse gases. URBEMIS uses the ITE Trip Generation Rate Manual and the Air Resources Board's (ARB) motor vehicle emissions model (EMFAC) to calculate transportation-related CO2 emissions and ARB's OFFROAD2007 model for CO2 emissions from off-road equipment. Area source outputs include natural gas use, landscaping equipment, consumer products, architectural coatings, and fireplaces. It also estimates construction impacts and impacts of mitigation options. Web site: http://www.urbemis.com.

Clean Air and Climate Protection (CACP) Software

This tool is available to state and local governments and members of ICLEI, NACAA, NASEO and NARUC to determine greenhouse gas and criteria pollutant emissions from government operations and communities as a whole. The user must input aggregate information about energy (usage), waste (quantity and type generated, disposal method, and methane recovery rate) and transportation (VMT) for community analyses. CACP uses emission factors from EPA, DOE, and DOT to translate the energy, waste and transportation inputs into greenhouse gas (in carbon dioxide equivalents) and criteria air pollutant emissions. If associated energy, waste and transportation reduction are provided, the model can also calculate emission reductions and money saved from policy alternatives. Web site: http://cacpsoftware.org.

Sustainable Communities Model (SCM)

This model quantifies total CO2e emissions allowing communities the ability to optimize planning decisions that result in the greatest environmental benefit for the least cost. Total CO2e emissions are based on emissions from energy usage, water consumption and transportation. The model provides an interactive comparison of various scenarios to provide environmental performance, economic performance, and cost benefit analysis.

Web site: www.ctg-net.com/energetics/documents/doc_SCM_070731.pdf

I-PLACE^{3}S

This model is an internet-accessed land use and transportation model designed specifically for regional and local governments to help understand how their growth and development decisions can contribute to improved sustainability. It estimates CO2, criteria pollutant and energy impacts on a neighborhood or

regional level for existing, long-term baseline and alternative land use plans. The data input requirements are extensive and require a fiscal commitment from the Metropolitan Planning Organization and its member local governments. Once the data is available, the IPLACES tool can be developed for that region relatively quickly, in approximately one week. The benefits include a multifunctional tool that provides immediate outputs to compare alternatives during public meetings, multilevel password protected on-line access, as well as providing access for local development project CEQA analyses. This tool also supports regional travel models and integrated land use and transportation assessments. Web site: http://www.sacregionblueprint.org/sacregionblueprint/the_project/technology.cfm and http://www.places.energy.ca.gov/places

CARROT

The California Climate Action Registry offers the Climate Action Registry Reporting On-Line Tool (CARROT) for Registry members to calculate and report annual greenhouse gas (GHG) emissions. CARROT calculates direct and indirect GHG emissions for the following emission categories by source: stationary combustion, process emissions, mobile source combustion, fugitive emissions and electricity use by source. It calculates emissions using entity collected data such as fuel purchase records, VMT and utility bills. While reporting and certification through CARROT is only available to members, the public may access entity reports online. Reporting protocols are also available to the public, including the General Reporting Protocol (www.climateregistry.org/docs/PROTOCOLS/GRP%20V2-March2007_web.pdf) and cement, forestry and power/utility sector protocols. Additional sector protocols are under development. Website: www.climateregistry.org/CARROT/

EMFAC

The Air Resources Board's EMission FACtors (EMFAC) model is used to calculate emission rates from all motor vehicles in California. The emission factors are combined with data on vehicle activity (miles traveled and average speeds) to assess emission impacts. The URBEMIS model described above uses EMFAC to calculate the transportation emission impacts of local projects. Web site: http://www.arb.ca.gov/msei/onroad/onroad.htm

Attachment 3

Examples of GHG Reduction Measures

The following are examples of measures that have been employed by some public agencies to reduce greenhouse gas emissions, either as general development policies or on a project-by-project basis. These are provided for illustrative purposes only.

LAND USE AND TRANSPORTATION

- Implement land use strategies to encourage jobs/housing proximity, promote transit-oriented development, and encourage high density development along transit corridors. Encourage compact, mixed-use projects, forming urban villages designed to maximize affordable housing and encourage walking, bicycling and the use of public transit systems.
- Encourage infill, redevelopment, and higher density development, whether in incorporated or unincorporated settings
- Encourage new developments to integrate housing, civic and retail amenities (jobs, schools, parks, shopping opportunities) to help reduce VMT resulting from discretionary automobile trips.
- Apply advanced technology systems and management strategies to improve operational efficiency of transportation systems and movement of people, goods and services.
- Incorporate features into project design that would accommodate the supply of frequent, reliable and convenient public transit.
- Implement street improvements that are designed to relieve pressure on a region's most congested roadways and intersections.
- Limit idling time for commercial vehicles, including delivery and construction vehicles.

URBAN FORESTRY

- Plant trees and vegetation near structures to shade buildings and reduce energy requirements for heating/cooling.
- Preserve or replace onsite trees (that are removed due to development) as a means of providing carbon storage.

GREEN BUILDINGS

- Encourage public and private construction of LEED (Leadership in Energy and Environmental Design) certified (or equivalent) buildings.

ENERGY CONSERVATION POLICIES AND ACTIONS

- Recognize and promote energy saving measures beyond Title 24 requirements for residential and commercial projects
- Where feasible, include in new buildings facilities to support the use of low/zero carbon fueled vehicles, such as the charging of electric vehicles from green electricity sources.
- Educate the public, schools, other jurisdictions, professional associations, business and industry about reducing GHG emissions.
- Replace traffic lights, street lights, and other electrical uses to energy efficient bulbs and appliances.
- Purchase Energy Star equipment and appliances for public agency use.
- Incorporate on-site renewable energy production, including installation of photovoltaic cells or other solar options.
- Execute an Energy Savings Performance Contract with a private entity to retrofit public buildings. This type of contract allows the private entity to fund all energy improvements in exchange for a share of the energy savings over a period of time.
- Design, build, and operate schools that meet the Collaborative for High Performance Schools (CHPS) best practices.
- Retrofit municipal water and wastewater systems with energy efficient motors, pumps and other equipment, and recover wastewater treatment methane for energy production.
- Convert landfill gas into energy sources for use in fueling vehicles, operating equipment, and heating buildings.
- Purchase government vehicles and buses that use alternatives fuels or technology, such as electric hybrids, biodiesel, and ethanol. Where feasible, require fleet vehicles to be low emission vehicles. Promote the use of these vehicles in the general community.
- Offer government incentives to private businesses for developing buildings with energy and water efficient features and recycled materials. The incentives can include expedited plan checks and reduced permit fees.
- Offer rebates and low-interest loans to residents that make energy-saving improvements on their homes.

- Create bicycle lanes and walking paths directed to the location of schools, parks and other destination points.

PROGRAMS TO REDUCE VEHICLE MILES TRAVELED

- Offer government employees financial incentives to carpool, use public transportation, or use other modes of travel for daily commutes.
- Encourage large businesses to develop commute trip reduction plans that encourage employees who commute alone to consider alternative transportation modes.
- Develop shuttle systems around business district parking garages to reduce congestion and create shorter commutes.
- Create an online ridesharing program that matches potential carpoolers immediately through email.
- Develop a Safe Routes to School program that allows and promotes bicycling and walking to school.

PROGRAMS TO REDUCE SOLID WASTE

- Create incentives to increase recycling and reduce generation of solid waste by residential users.
- Implement a Construction and Demolition Waste Recycling Ordinance to reduce the solid waste created by new development.
- Add residential/commercial food waste collection to existing greenwaste collection programs.

Forests: Opportunities for Greenhouse Gas Emission Reduction in Sonoma County

Community Climate Action Plan

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Table of Contents

Introduction 1
Background 1
Forest and Climate Opportunities and Actions for Sonoma County 2
Research and Policy Recommendations 4
Conclusion 6

Forests: Opportunities for Greenhouse Gas Emission Reduction in Sonoma County

Introduction

Sonoma County's natural endowment of forestland offers the County a significant opportunity to include its forestlands in countywide efforts to meet its greenhouse gas emission reduction goals. This report provides an overview of the connection between forests and global warming, the general types of forest activities that produce climate benefits, and recommendations that the County should implement to engage the forestland base more effectively to fulfill its climate change objectives. Specifically, these recommendations are:

1) Performance of additional research to establish a countywide forest carbon baseline and monitoring process to track overall performance in the forest sector
2) Establishment of an overall emissions reduction target and emissions "floor" for the forest sector to complement the County's overall greenhouse gas reduction goals
3) Adoption of additional regulatory and incentive-based policies, including zoning, conservation easements and fees, related to greenhouse mitigation and land use planning

Background

Forests are both a part of the global warming problem and part of the solution. Unlike other emission sectors, forests have the unique capacity to remove carbon dioxide (CO_2) from the atmosphere and store this gas as carbon for long periods of time in their biomass (e.g., trunks, branches, leaves, roots, etc). In fact, California's coastal redwoods (sequoia sempervirens), like those in Sonoma County[1], are capable of absorbing and storing enormous amounts of carbon for hundreds, if not thousands, of years.

While forests are a natural CO_2 reservoir, or "sink", they are also a source of CO_2 emissions. On a global level, forests are responsible for roughly 20 – 25% of overall CO2 emissions, largely to due conversion of forestland and the associated depletion of carbon stocks. When forests are disturbed through events such as conversion to development or agriculture, fire or harvest, the carbon that is stored in tree biomass is emitted to the atmosphere. When harvested for timber, a percentage of forest carbon is

[1] According to Save the Redwoods League there are roughly 3,000 to 4,000 acres of old-growth redwoods left in Sonoma County today, which is substantially less than their historic extent. Personal correspondence with Laura Kindsvater, July 31, 2007.

stored in wood products for periods of time. These wood products decay over time, releasing CO_2 at an average decay rate of 2% annually.[2]

Given forests' unique capacity to be a greenhouse gas (GHG) emissions source and sink, they can and should play a critical role in global warming mitigation policy both nationally and locally. Through forest activities, such as changes in forest management, forest restoration and conservation, direct CO_2 emissions from forests can be prevented and minimized and additional CO_2 can be removed from the atmosphere and stored in our forests. Restoration and management for retention of bigger trees and older forests[3] can result in greater amounts of CO_2 removed from the atmosphere than what would occur otherwise. Furthermore, forests can be protected from conversion to other uses and development patterns can be managed to minimize emissions that result directly from forestland conversion to non-forest uses. Such activities would foster not only the climate benefits of forests, but also the many other public benefits that forests provide – such as water quality, biodiversity, recreation, forest economies and wildlife habitat.

Forest and Climate Opportunities and Actions for Sonoma County

With approximately 480,000 acres of forestland[4] within its boundaries, including oak woodlands and productive timberland, Sonoma County has an opportunity to take specific measures to incorporate its forestlands in its climate change goals. The County has roughly 375,000 acres of land that is capable of growing timber (and hence, sequestering more carbon), with 230,000 acres that are currently functioning as timberland.[5] These lands can be conserved to minimize the CO_2 emissions associated with conversion of timberland to other uses, such as vineyards. Additionally, these lands can be restored and managed to remove additional CO_2 from the atmosphere, while also providing wood products and many other public benefits. Likewise, the County can protect and restore its oak woodlands to maintain and enhance the climate service that its oak woodlands provide.

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[2] Turner, D.P. et al. 1995. A carbon budget for forests of the coterminous United States. Ecological Applications 5(2):421. Turner, D.P. et al. 1995. A Carbon sequestration by forests of the United States: current status and projections to the year 2040. Tellus 47B:232. Harmon, M.E., B. Marks, N.R. Hejeebu. 1996. A users guide to STANDCARB version 1.0: a model to simulate the carbon stores in forest stands. Department of Forest Science, Oregon State University, Corvallis, Oregon.

[3] The management for older forests (i.e., greater carbon stocks on the landscape) can include the production of wood products and the remaining carbon value that wood products hold.

[4] Please note that the term forestland is a broad definition that includes all forest types in the county. Statistics for timberlands and oak woodlands in this paper are subsets of this larger definition and due to differences in definitions, the numbers will not total 480,000 acres

[5] Sonoma County Permit and Resource Management Department, Memorandum from David Schiltgen: Regulating the conversion of timberlands to nontimber uses, June 20, 2002

Minimize and prevent direct greenhouse gas emissions associated with forestland conversion to other uses

Over the past several years, Sonoma County has witnessed an increasing threat of forestland conversion to non-forest uses, vineyards in particular. Between 1990 and 1997, at least 1,630 acres of dense oak woodlands were converted to vineyards[6] and from 1989 to 2004, 851 acres of timberland were approved for conversion, primarily to vineyards. More recently, an application to convert approximately 1,700 acres of forestland to vineyards has been submitted to the County, which is still pending. According to Sonoma County's Permit and Resource Management Department, once the time and money has been invested to convert timberland to croplands, these lands are almost never restored to forests.

The climate impacts of this forestland conversion are twofold. First, the conversion of these forestlands results in direct emissions of CO_2 to the atmosphere. Second, the future capacity of the forest to remove additional CO_2 from the atmosphere is significantly diminished because there is very little chance that these lands will be restored to forests based on the history of conversions in Sonoma County. The potential net difference between the overall carbon stored in a vineyard and forestland could be anywhere from 15 tons of carbon per acre to over a thousand tons per acre, depending on several factors, including forest type, age, site class and maturity and management of the vineyard. Such a reduction in overall carbon stocks means net emissions of CO_2 to the atmosphere upon conversion of the forestland to vineyards. Likewise, net emissions can occur upon conversion of forestlands to other kinds of developed uses, like commercial or residential development.

A more refined analysis based on the specific forest carbon inventories of the converted forestland and subsequent carbon sequestered by the vineyard would provide a better estimate of net CO_2 emissions and foregone future sequestration caused by these conversions and depletion of forest carbon stocks. California, at the state level, is conducting a similar analysis pursuant to its recently adopted Global Warming Solutions Act of 2006, and could act as a conceptual model for how Sonoma County could perform these inventories at the County and landowner levels. Such an analysis would also give Sonoma County a better sense of the greenhouse gas emissions it could prevent through existing or new policies that minimize forestland conversion (see research and policy recommendation section).

Remove additional carbon dioxide from the atmosphere by restoring and increasing forest carbon stocks across the landscape

The County could also help meet its greenhouse gas emission reduction targets through activities that restore and increase forest carbon stocks on the landscape in existing forested areas and where forests once existed that are no longer in forest cover. Efforts

[6] Merenlender, Adina and Brooks, Colin. GIS in Rangeland Management, Vineyard Expansion in Sonoma County: Mapping, Monitoring, and Changing Policies

like this have been taking place in the County and additional ones could be facilitated. For instance, Creighton Ridge near Cazadero is undergoing active reforestation after losing its forest cover to a fire in 1978. The loss of this forest during the fire resulted in direct CO_2 emissions to the atmosphere (i.e., the stored forest carbon was emitted to the atmosphere). Restoration efforts are helping to restore the forest carbon stocks that this area once held, resulting in the absorption of CO_2 from the atmosphere as the restored forest area grows and matures. The County, using established greenhouse gas accounting protocols like those developed by the California Climate Action Registry, could quantify the climate benefits of this reforestation. With the help of other local partners, including the Sonoma County Open Space District, Sonoma Land Trust, and landowners, the County could also identify additional areas in the County that would benefit from reforestation, whether they are previously burned areas that have not recovered or areas that are out of forest cover due to other types of disturbances or activities.

In addition, with roughly 230,000 acres of functioning timberland, the County could implement incentives and policies to encourage forest management practices to increase overall forest carbon stocks in these areas. Management activities to increase overall forest carbon stocks could include restocking under-stocked areas and managing for older forests, while still producing wood products. A recent example from Humboldt County is the van Eck forest management project. This project is registered with the California Climate Action Registry,[7] and through changes in forest management, the project is anticipated to absorb and store over 500,000 tons of additional CO_2 during the project's lifetime. The project continues to be managed for wood products, but is also providing significant climate benefits, as well as enhanced protection for fish and wildlife. Projects like van Eck are also possible in Sonoma County and could be quantified using the California Climate Action Registry's Forest Protocols.

Research and Policy Recommendations

To incorporate the forest sector most effectively in global warming mitigation strategies, the County should undertake a series of actions to attain a better sense of greenhouse gas reduction potential and monitor progress over time.

Establish a countywide forest carbon baseline and monitoring plan

A countywide baseline and monitoring plan would provide the basis for tracking overall emissions and reductions within the forest sector in Sonoma County. As mentioned earlier, this countywide survey could also identify the most appropriate areas for restoring forests, avoiding or minimizing emissions due to conversion, and changes in forest management to increase overall forest carbon stocks. In this effort, the County could partner with local organizations, such as land trusts, landowners and other individuals to gather information.

[7] The California Climate Action Registry (www.climateregistry.org) is a voluntary greenhouse gas registry, which was established by California statute as a non-profit organization. The Registry provides standardized greenhouse gas accounting protocols to quantify greenhouse gas emissions from a variety of sectors, including forests, and emission reductions from forest projects.

The countywide forest carbon assessment and baseline could be established through aerial surveys or satellite imagery and substantiated with sample plot data. The County could also join the California Climate Action Registry and use its Forest Protocols to estimate and track changes in overall forest carbon stocks for at least the County's forestlands. Private landowner level emissions and emission reductions can also be effectively monitored through the California Climate Action Registry to the extent landowners join the Registry.

Establish an overall emissions reduction target and "floor" for the forest sector

The County should seek to establish an overall greenhouse gas reduction target for the forest sector to serve as an incentive to develop policies and programs that include the forest sector in climate change mitigation objectives. The forest sector emissions reduction goal could be developed once the county establishes a baseline for its forestlands as described earlier. Such a goal should be reflected as an overall cumulative forest carbon stock number to account for the permanence or sustainability of reductions within the forest sector. Once the County attains a better sense of where reduction opportunities exist across the landscape, sub-goals or targets, based on particular forest activities, could also be established (e.g., tons of reductions pursuant to reforestation, changes in management or conservation (avoided conversion).

The County should also consider establishing a forest "floor" or cap for the forest sector to protect against forestland conversion and substantial depletion of forest carbon stocks. Such a floor would effectively limit the amount of human-caused emissions from the forest sector by 1) limiting the amount of forestland that can be converted to other uses and 2) requiring emissions mitigation for any lands that are converted to a non-forest use.

The County could establish a floor by enhancing, or using as a model, its recent ordinance (No. 5651) to mitigate timberland conversion. Such limitations on conversion could be extended to include CO_2 emissions with a 1:1 ratio. The County could also amend the general plan and revise the timber production zoning district to disallow conversion of timberland and do comparable zoning for oak woodlands and other critical natural resource areas.

Facilitate the increased use of conservation easements through zoning, dedication of public funds and mitigation fees

The increased use of conservation easements in the County to minimize forestland conversion and encourage greater overall forest carbon stocks could provide significant, permanent climate benefits. To encourage greater use of easements, the County could enhance zoning laws to promote cluster development to minimize conversion pressure on forested lands and identify and establish "climate reserve" zones on forestlands that are secured with conservation easements. The Sonoma County Open Space District and other local land trusts could be key partners to help identify and establish these climate reserve zones. To quantify the climate benefits of these reserve zones, the county could

rely on its countywide monitoring as described earlier or it could register these lands with the California Climate Action Registry (or some combination of the two).

To support an overall cap on forest-based emissions, the County can require the quantification and mitigation of CO_2 emissions that result from forestland conversion to non-forest uses. As mentioned earlier, recent proposals to convert forestlands to vineyards could include requirements of CO2 mitigation either directly or through payment of a fee that would be invested in mitigation projects. Such mitigation projects should, among other things, be registered and certified with the California Climate Action Registry to ensure that any permitted mitigation produces real, permanent and verifiable reductions. Furthermore, mitigation requirements should not only consider direct emissions associated with conversion but also any foregone future climate benefits (additional sequestration) that the forest could have provided.

The County could look to its jobs-housing linkage fee as a model for conversion mitigation fees. Similar to this program, a fee could be assessed for new residential development (excepting low-income and high density) or development to other uses. This fee, in turn, can be dedicated to a fund to invest in forest-based GHG mitigation projects, which may include a "climate reserve" as mentioned earlier.

Adopt the Coast Forest District's Southern Subdistrict harvest rules

The County could also seek to incorporate the Coast Forest District's Southern Subdistrict harvest rules of the California Forest Practice Rules. Adopting the special harvesting methods for this subdistrict would encourage the retention of greater overall forest carbon stocks on timberlands compared to the current applicable rules for Sonoma County.

Conclusion

As Sonoma County seeks to reduce its carbon footprint and meet its greenhouse gas reduction targets, it should take advantage of greenhouse gas reduction opportunities that are available in the forest sector. The County can include its forestlands in climate change mitigation policies and programs. To do this most effectively, the County will need to take steps to gather forest carbon data to establish a countywide forest carbon baseline and target. It should also adopt an accounting and monitoring process to track carbon dioxide emissions and reductions from forests. Some of the most effective and accessible policy tools to achieve reductions in the County include zoning ordinances, conservation easements and mitigation fees. These actions would foster significant climate benefits, as well as a host other much-needed public benefits.