

Science

FINDINGS

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“Science affects the way we think together.”

Lewis Thomas

CLIMATE CHANGE AND CALIFORNIA: POTENTIAL IMPLICATIONS FOR VEGETATION, CARBON, AND FIRE



Oak woodlands (left) and alpine meadows (right) are two ecosystems threatened by climate change.

“...science works like a telescope pointing toward reality; or, turned around, a microscope to dissect details and analyze causes.”

—Richard Dawkins

Nature, as a rule, is resilient. The evolution of life has selected for those species and processes that can take a beating and keep coming back. Nonetheless, every ecosystem has a threshold, beyond which native species and communities start to crash. In the approaching decades, the resilience of California’s ecosystems—including some of the world’s most diverse forests, shrublands, and grasslands—could be tested by a potentially serious one-two punch: urbanization and global warming.

A changing climate in California was recently the subject of one of the most integrated and detailed assessments of global

warming ever conducted. The study was unique in that it didn’t ask, as most do: “What will the impacts of climate change be?” Instead, the researchers sought a more nuanced perspective; they asked: “What are the consequences of following markedly divergent pathways of greenhouse gas emissions?” California was the focus.

And although climate change is a global phenomenon, California made an ideal case study. “There is more diversity in the state’s landforms, climate, ecosystems, and species than in any comparably sized region in the United States,” says James Lenihan, a research ecologist at the PNW Research Station in Corvallis, Oregon. “In addition, California has large urban centers, such as Los Angeles and San Francisco, is home to 34.5 million people, and has the fifth-largest economy in the world. By examining the effects of climate change on such a wide diversity of human and ecological systems,

IN SUMMARY

Nineteen scientists from leading research institutes in the United States collaborated to estimate how California’s environment and economy would respond to global climate change. A scientist from the PNW Research Station led efforts to estimate effects on vegetation, carbon, and fire.

To quantify the range of the possible effects of climate change over the next century, researchers used state-of-the-art climate change simulations coupled with a dynamic vegetation model to gauge sensitivity of natural ecosystems in California under several climate scenarios.

The results suggest that climate change would have a more pervasive impact on the vegetation community diversity than would urbanization. Vegetation is estimated to migrate to higher elevations, which would result in reductions in the area covered by alpine meadows and subalpine forests. The area of commercially-important softwood tree species and the state’s signature woodlands and shrublands are predicted to decline with warming.

Climate change could also affect fire frequency and the area burned annually, with most of the scenarios resulting in increased fire. Finally, the simulations showed that reducing emissions of carbon dioxide over the next several decades could buffer the longer term impacts of global warming.

our methods and results can be broadly applied outside of California.”

Nineteen scientists from leading research institutions in the United States collaborated to develop estimates of how California’s environment and economy will respond to climate change. Their findings were recently published in the *Proceedings of the National Academy of Sciences*, and were the subject of congressional hearings in Washington, D.C. Lenihan was primarily responsible for estimating effects on vegetation distribution, carbon, and fire.

“The state’s burgeoning population already affects much of California’s biological wealth. Natural habitats have been and continue to be altered and fragmented. Most of the state’s forests have been logged, native oak woodlands are in serious decline, native grasslands have almost completely disappeared, and nearly 90 percent of the state’s wetlands and riparian areas have been degraded or destroyed,” says Lenihan.



KEY FINDINGS



- Higher temperatures and wetter conditions are estimated to result in expansion of forests at the expense of alpine meadows, woodlands, and shrublands, and the expansion of grasslands at the expense of arid land vegetation. In contrast, drier scenarios result in grasslands advancing into the simulated historical range of woodlands and shrublands, even in the central and northern regions of the state.
- Climate change would affect the annual area burned and the frequency and intensity of fires, with most of the scenarios resulting in increased fire. However, change in fires is not significant until the latter part of the century. The drier scenarios result in more frequent fires and more area consumed by fire annually. The wetter scenarios result in larger and more intense fire than those that have occurred in the simulated historical record because under the wetter scenarios more fuel accumulates and then burns during the occasional dry years.
- Both wetter and drier scenarios result in increases in carbon storage in California vegetation of between 3 and 6 percent. The wetter scenarios result in increases of total ecosystem carbon, with greater increases in carbon stored in vegetation. The dry scenarios also result in increases in total carbon storage, with greater increases in soil carbon.

A RANGE OF POSSIBILITIES

Predicting a century of climate change is a delicate business fraught with uncertainty. Analysts must make assumptions every step of the way—each carrying a potentially large influence. One big assumption built into climate predictions is: How much heat-trapping carbon dioxide (CO₂) will be released into the atmosphere?

Lenihan and his colleagues took a precautionary approach. They chose to bracket the variability in their predictions. They first used a “business-as-usual” estimate of CO₂ emissions—essentially a continuation of the current output. Then, they took a “greener” perspective on future pollution, an estimate that assumed a more conservation-oriented approach to energy use. “At the time, this was a fairly novel approach; before our project, the “business as usual” estimate was all that was usually examined,” explains Lenihan.

They also took a cautious approach to modeling the future climate. Climate change is most effectively calculated through Global Circulation Models (GCM). These state-of-the-art programs run on super computers at a few dozen research institutions around the world. They predict how the climate system, e.g., temperatures, humidity, clouds, and rainfall, responds to changes in

the chemical composition of the atmosphere. Each GCM produces slightly different results, reflecting the differences in assumptions that went into their construction. Rather than put their trust in one GCM, Lenihan and his colleagues chose two: one that was very sensitive to the concentration of CO₂ in the atmosphere (the Hadley GCM), and one that was less sensitive (the Parallel GCM).



Commercially valuable conifer forests (left) are anticipated to be replaced by mixed evergreen forests (right) as temperatures continue to rise.

Purpose of PNW Science Findings

To provide scientific information to people who make and influence decisions about managing land.

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To show the range of pathways that California's vegetation might take in response to climate change, Lenihan used four climate predictions—one high- and one low-emission scenario from each GCM.

“All simulations showed a significant increase in average temperature by the end of the century, but the ‘business-as-usual’ estimate produced increases nearly twice as high as the ‘green’ estimate,” says Lenihan. It took until the midcentury for the benefits of conservation to become apparent. Simulated climate change through the first 50 years was reacting to today's emissions.

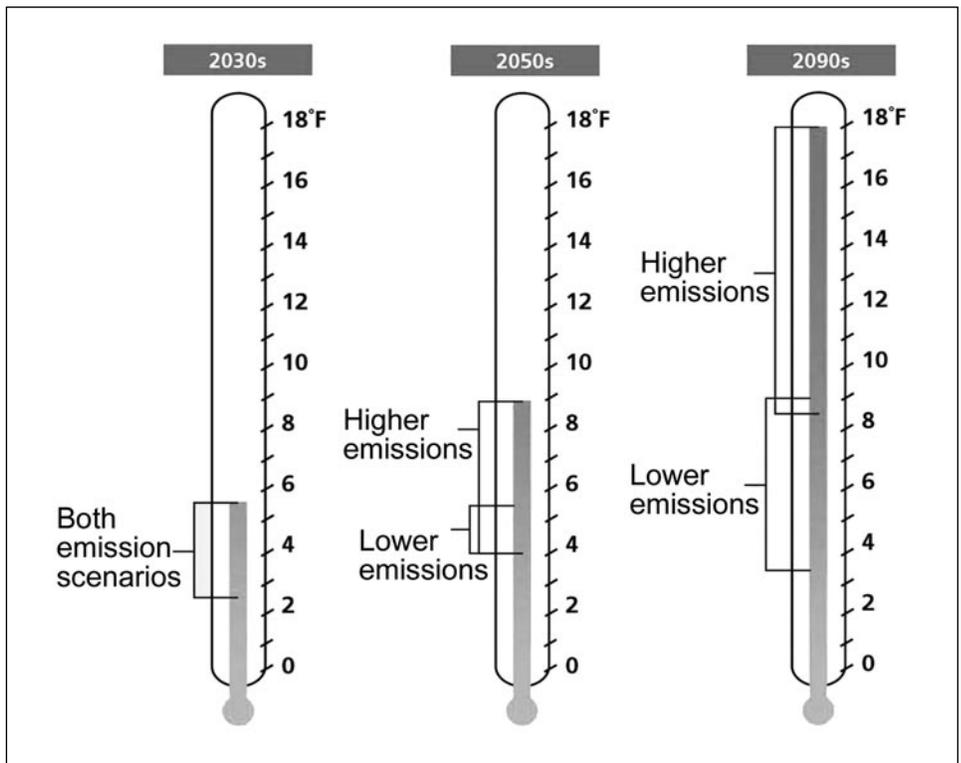
Interestingly, although the GCMs were in general agreement about rising California temperatures, they differed with regard to precipitation; the more sensitive model predicted a drier climate, whereas the other predicted more rainfall.

The range of predicted climates simulated under the four scenarios resulted in widely disparate vegetation patterns. “Wetter conditions are estimated to result in expansion of forests, primarily at the expense of shrublands and woodlands, and the expansion of grassland in some of the most arid regions of the state. In contrast, drier scenarios resulted in grasslands advancing into the historical range of woodland and shrubland,” explains Lenihan.

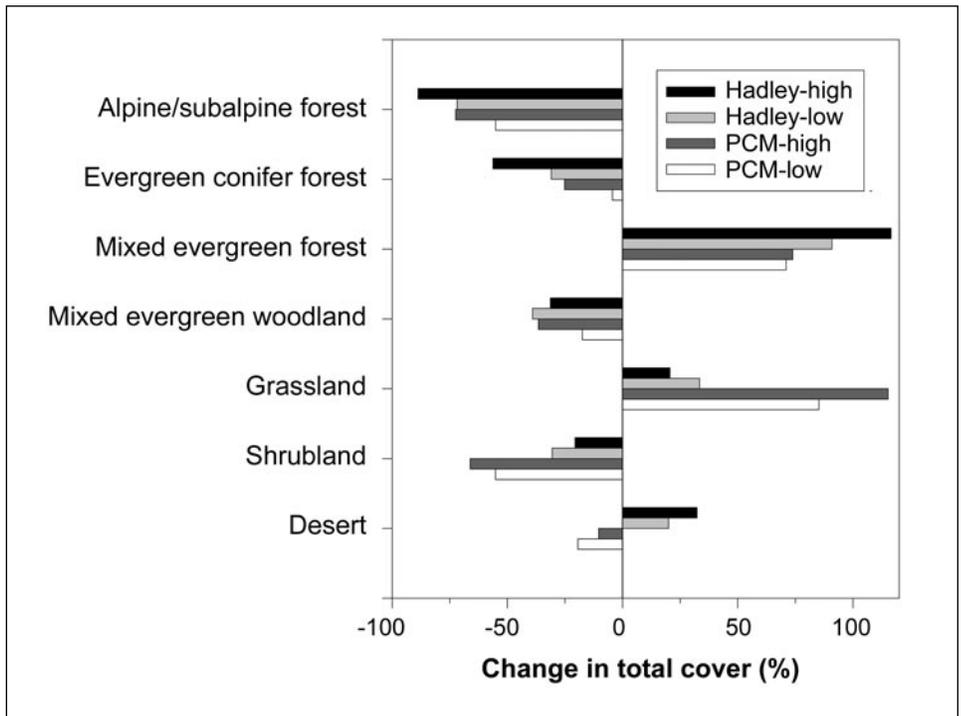
But Lenihan concedes some generalities: “If you were to fly over mountainous regions of California, in 100 years, it would look as if the vegetation had shifted upward. Alpine regions, where the growing season is currently too short to support much tree growth, would be invaded by conifer forests, which now dominate the midelevations. And mixed-evergreen forests, composed of hardwood species such as tanoak and madrone, which are less tolerant of deep winter frosts, would have also moved upslope, replacing conifer forests, as temperatures rise,” he says.

HOT AND WET OR HOT AND DRY?

Small differences in precipitation, particularly in the winter, can result in large differences in vegetation patterns. California's signature oak-woodlands are a classic precipitation-driven ecotone. In the lowlands, where rainfall is limiting, the landscape is dominated by rolling grasslands with a few scattered oaks. Move up in elevation and along the precipitation gradient, and there you'll find a greater density of oaks. Higher still, where annual rainfall is less limiting, the trees become increasingly common. Eventually, grasses are totally out-competed and give way to a closed-canopy forest.



Projected increases in statewide average annual temperatures for three 10-yr periods. Ranges for each emission scenario represent results from two climate models.



Statewide change in cover of major vegetation types simulated at the end of this century relative to their historical cover.

Precipitation gradients such as this exist throughout California. For that reason, the effect of climate change on future precipitation will, in large part, dictate the distribution of vegetation.

“The most prominent simulated response to a drier climate was the advance of grasslands into the range of woodlands and shrublands,” says Lenihan. “This transition was prompted by a decline in the competitiveness of woody

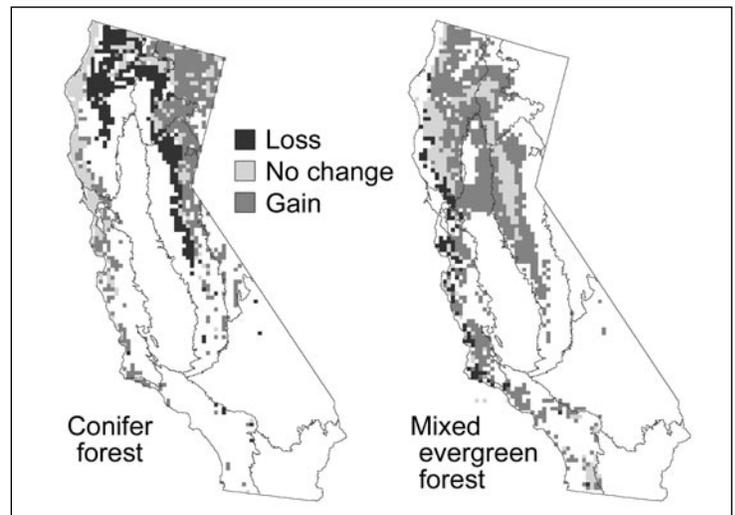
plants as a response to the decline in dormant season precipitation and an increase in fire. In contrast, a wetter climate results in widespread advancement of forests into regions now dominated by shrubs and grasses. But in other regions grasslands also expand, particularly in the southern end of the Great Central Valley and in the uplands of the Mojave Desert where grasses replace desert.”

Interestingly, both the wetter and drier scenarios resulted in more fire by the end of the 100-year simulations, although the character of the predicted fire regimes differed markedly. In a hotter and drier climate, fires would occur more frequently than they do today, and more area would burn annually. This scenario favors the expansion of grasslands, which maintain most of their biomass underground, allowing them to reestablish quickly after fire.

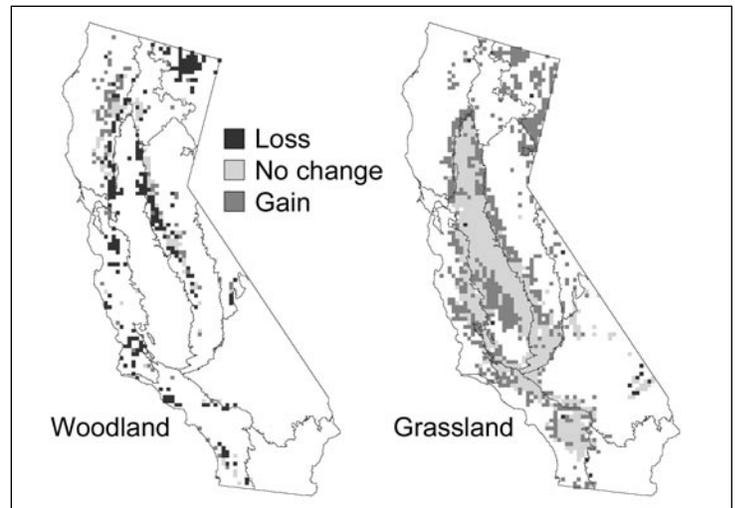
In contrast, the wetter climate scenario resulted in increased plant growth and an initial decrease in fire activity. Over time, however, the continual buildup of fuels set the stage for very large fire events coinciding with the occasional dry summer. “This interaction between fuels and the annual variability in precipitation produced greater year-to-year variability in area burned, and the somewhat counterintuitive result of more severe fires simulated under the wetter scenario than under the drier scenario,” explains Lenihan.

Carbon storage is another topic in which Lenihan’s analysis yielded surprising results. As is commonly known, excess CO₂ in the atmosphere is believed to contribute to climate change. One way to buffer climate change, therefore, is to retain as much carbon on the ground as possible, typically in the form of plant biomass. This is referred to as carbon sequestration.

“Whereas we expected greater carbon storage due to increased plant growth under a warmer and wetter climate, we were somewhat surprised to find an increase in sequestration under the warmer and drier climate,” says Lenihan. “Productivity was maintained by a shift in vegetation composition towards grasses, which are more tolerant of drought and frequent fire, and more effective contributors to belowground carbon stocks. Moreover, the drier conditions slowed decomposition, thereby reducing losses of soil carbon to the atmosphere.” However, Lenihan was quick to point out that climate scenarios somewhat drier than those examined in this study would likely result in a simulated loss of total carbon storage.



Changes in the distribution of conifer and mixed evergreen forest at the end of this century simulated under the Hadley high-emissions climate scenario.



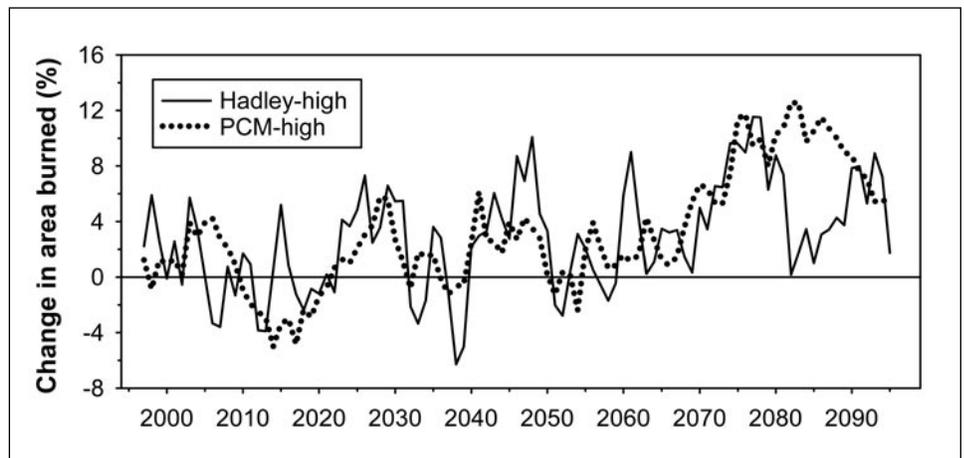
Changes in the distribution of woodland and grassland at the end of this century simulated under the PCM high-emissions climate scenario.

THE ECONOMICS OF WARMING

All ecosystems of California, whether managed or unmanaged, would likely be affected by climate change,” says Lenihan. This is a powerful statement in a state whose economy includes more than a few climate-sensitive industries. Indeed, California’s agricultural sector alone tops \$30 billion annually, more than any other state.

Given an anticipated 4- to 6-degree Fahrenheit rise in average temperature over the next century, the future of California’s crops is worth considering.

Lenihan teamed with Robert Mendelsohn at the Yale School of Forestry to give specific attention to projections of commercial forest. “Our results suggest changes in both the



Results suggest that the area burned across the state will increase during the latter half of the next century.

distribution and productivity of commercial softwood species, such as Douglas-fir and redwood. The area of softwoods is predicted to decline with warming. By the end of the century, this loss in area outweighs predicted increases in softwood productivity, suggesting the long-term total supply in California will decline,” says Lenihan.

Global warming would affect the state’s water supply. Even in scenarios with increased precipitation, warmer temperatures result in rain where there once was snow. Reductions in Sierra snowpack and earlier spring runoff could have cascading impacts on streamflows and water storage and supply, creating higher demand for irrigation.

The broader study concludes: “The overall magnitude of impacts on water users depends on complex interactions between temperature-driven snowpack decreases and runoff timing, precipitation, future population increases, and human decisions regarding water storage and allocation.”

In addition, rising temperatures, irrespective of changing water supply, would affect several crops. For example, California’s celebrated wine industry is expected to be hit quite hard in all but the coolest grape-growing regions.

WAKE-UP CALL

The research offers several points of optimism. “For one, although there were several notable differences, the overall distribution of vegetation simulated in our study was not all that different from the current condition,” says Lenihan.

Furthermore, the research showed the positive effects of curbing emissions of greenhouse gases. “The loss of alpine habitat, the loss of woodland and shrubland under the drier climate scenarios, and the reduced extent of important timber species would all be ameliorated under the greener emission scenario” says Lenihan. Although some damage may have already been done, the future climate could still be influenced by future changes in energy use.

In this respect, the study is a wake-up call for those in California and around the world. Indeed, Lenihan and his colleagues were initially funded by the state of California. “The goal was to help California’s natural resource managers and policymakers better understand the potential effects of climate change on

 LAND MANAGEMENT IMPLICATIONS 
<ul style="list-style-type: none"> • Natural ecosystems of California, whether managed or unmanaged, are likely to be affected by climate change. Land managers can use these simulation results to anticipate likely changes in local natural resource conditions.
<ul style="list-style-type: none"> • Simulated ecosystem response to climate change identified several habitat types, such as alpine meadows, oak woodlands, and coastal chaparral that would be hit hardest by global warming. This provides natural resource managers an opportunity to protect and restore the most threatened regions.
<ul style="list-style-type: none"> • This study provides specific information for fire and timber management, conservation of biodiversity, and carbon sequestration. These findings have been made available to natural resource policymakers to guide the development of adaptive management strategies that reduce the state’s vulnerability to climate change.
<ul style="list-style-type: none"> • This study provides a starting point for assessing the outcome of changes in greenhouse gas emissions trajectories driven by climate-specific policies, and the extent to which lower emissions can reduce the risks of human-caused interference with the climate system.

As average temperatures rise, so too would the incidence of summer heat waves; the most dramatic increases in simulated heat waves occurred under the “business-as-usual” scenario. The National Academy of Sciences report concludes: “Heat waves will likely

occur more frequently and last longer.” Los Angeles is cited as an example where: “Heat waves are expected to increase by four times under the ‘green’ scenario and six to eight times under the ‘business-as-usual’ scenario.”

the state,” says Lenihan. But soon after they released their preliminary findings, the scope of their audience expanded.

The research was soon sponsored by the Union of Concerned Scientists. This, in turn, piqued the attention of the mainstream media, who gave wide coverage to the findings. In the months to follow, the story of the potential impacts of climate change on California was told around the world, having been featured by Cable News Network, National Public Radio, The Wall Street Journal, and dozens of other media outlets.

Policymakers and the public continually make decisions related to climate change. This study strives to inform these decisions. For some, it may be a call to action.

“This is one of the great advantages of a computer model—the computer faithfully tells you the exact implications of your assumptions, whether you like them or not.”

—Daniel B. Botkin

FOR FURTHER READING

- Lenihan, J.M.; Drapek, R.; Bachelet, D.; Neilson, R.P. 2003. *Climate change effects on vegetation distribution, carbon, and fire in California*. Ecological Applications. 13(6): 1167–1681.
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analysis in several of California's national parks. His current research focuses on seasonal fire forecasting and the continued development of general dynamic vegetation models. Lenihan earned B.S. and M.S. degrees from Humboldt State University and a Ph.D. in geosciences from Oregon State University.

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