Pacific
Northwest
Research
Station

Science Update

WESTERN FORESTS, FIRE RISK, AND CLIMATE CHANGE

IN SUMMARY

Climate warming may first show up in forests as increased growth, which occurs as warmer temperatures, increased carbon dioxide, and more precipitation encourage higher rates of photosynthesis. The second way that climate change may show up in forests is through changes in disturbance regimes—the long-term patterns of fire, drought, insects, and diseases that are basic to forest development.

Advanced computer models are producing the first national-scale simulations of how ecosystems and fire regimes could change in the 21st century. In six of seven future scenarios run through one model, the Western United States gets wetter winters and warmer summers throughout the 21st century (as compared to current climate), with expanded woody growth across the West and thus, increased fire risk. These results have been used in national and global assessments of global climate change.

The computer model can now produce 7-month forecasts of possible fire risks for the conterminous United States, made possible by incorporating year-to-year changes in climate, fuel loadings, and moisture into the model. The accuracy of 2002 and 2003 forecasts has validated the model's approach, suggesting it can eventually be a useful planning tool for fire managers.

Research results were produced by scientists from the USDA Forest Service Pacific Northwest (PNW) Research Station, working with others from Oregon State University and from around the world. The team's research has led to the key insight that fire and fuel load issues in Western forests are linked to global carbon balance issues. The full story is inside.

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Key Findings

- Along with fire suppression, a strong climate change signal is associated with woody expansion in the West—the spread of juniper into grasslands and increased understory growth in conifer forests. The woody expansion is projected to continue throughout the 21st century owing to continuing climate change and elevated levels of carbon dioxide in the atmosphere. Although total precipitation is projected to increase, most will fall in the traditional wet season and summers are likely to be hotter and longer than they are currently. Thus increased precipitation would contribute to woody expansion but likely would not reduce summer fire risk.
- Climate variability is strongly related to when, and in which region, large fires have occurred over the last 100 years, in the conterminous United States. Large fires associated with climate patterns include the 1910 Idaho fires, 1988 Yellowstone fires, and 2002 Biscuit Fire in southwest Oregon.
- The MC1 model produces 3- to 7-month forecasts of fire risk for the conterminous United States. The forecasts are the first national-scale, high-resolution forecasts of fire risks in the United States that incorporate climate-driven, year-to-year changes in fuel loadings and moisture characteristics. As fire risk forecasts are further validated and improved, they may become useful tools for managers.
- In the conterminous United States, ecosystems were a likely source of carbon to the atmosphere through much of the 20th century because of several major droughts. (This analysis does not include timber harvest, car and factory emissions, cities, or other human impacts on carbon release.) When the climate regime shifted in the mid-1970s to a multidecadal wet period, simulations suggest that the natural U.S. ecosystems became a net sink for carbon, meaning that more carbon was pulled into ecosystems than was released into the atmosphere. Much of this carbon was stored as woody growth in the West.
- The fire and fuel load issues in Western forests are linked to global carbon balance issues. Carbon budgets will likely become part of forest management planning. Challenges would be to:

  (1) In the West, reduce wildfire risk even as fuel loads increase because of increased seasonal precipitation.

  (2) In the Southeast, reduce risk of rapid conversion of forests to savannas and grasslands.

  (3) In the entire United States, balance carbon storage in forests with reducing fire risks from fuel accumulation.

How does long-term climate change affect forests and other ecosystems?

The most obvious effect is the slow migration of forests. Over the millennia, forests have retreated southward during ice ages and shifted slowly as glaciers retreated and rainfall patterns changed.

Climate change affects forests in other ways, however—ways both less obvious and more immediate. The research problem of understanding these influences was approached by the Mapped Atmosphere-Plant-Soil System (MAPSS) team led by Ron Neilson, in PNW Research Station's Managing Disturbance Regimes Program. The project was named the vegetation/ecosystem modeling and analysis project.

The team built a computer model that predicts the potential vegetation that would grow naturally in an area if there were no agriculture or cities. For potential vegetation, climate (water and temperature) and soils are the most important factors affecting large-scale patterns of what grows where, and how fast it grows. Vegetation was classified in broad types, such as "coniferous forest" and "temperate deciduous forest."

"The original model was a steady-state model," explains Jim Lenihan, fire and ecosystem modeler on the team. "The computer 'drew' the map under average climate conditions for the conterminous United States."

Computer models can incorporate enormous amounts of data and apply complicated sets of equations and rules to the data, a process involving millions of calculations (see sidebar on facing page). The MAPSS model, a steady-state model, includes a set of equations not only for basic water input such as rain, snow, and snowmelt, but also for factors such as plant transpiration, soil infiltration, leaf form, and even leaf fall. MAPSS calculates the type of vegetation that could grow in a place (if there were no human influence), its density in a ratio of leaf area to ground area, and a water balance, including soil moisture and runoff.

Purpose of PNW Science Update

The purpose of the *PNW Science Update* is to contribute scientific knowledge for pressing decisions about natural resource and environmental issues.

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What Computer Modeling Can—and Cannot—Do

Controlled experiments on forests and climate change would require controlling all variables, including weather, over a large landscape for decades. Because that would be impossible, scientists use computer models as tools to study climate change. No single model can simulate everything. Scientists design different types of models to study climate, ecosystems, vegetation dynamics, and biogeography, and increasingly, scientists are linking these models to study interactions among factors.

To build ecosystem models, scientists use field and laboratory findings about carbon, water, and nitrogen interactions in ecosystems. For example, trees generally respond to elevated levels of carbon dioxide with increased rates of photosynthesis and tree growth, although a scarcity of nutrients, particularly soil nitrogen, can limit this growth. Water-use efficiency typically increases in carbon dioxide-enriched atmospheres. Elevated carbon dioxide may alter tree resistance to pests and even influence the rates of decomposition in soils. The models incorporate data on trees' responses to carbon dioxide, weather patterns, climate patterns, ocean surface temperatures, and so forth. Temperature warming alone would not cause the woody expansion predicted by models; the elevated level of carbon dioxide is a key factor in the simulations. Data also exist on how human activities affect specific drivers of climate, such as greenhouse gases.

Each type of model is built from databases and experimental findings relevant for its area, such as climate or vegetation. A computer model is a synthesis of the best available existing information. Using their best knowledge, scientists develop a set of mathematical rules, or algorithms, by which the computer model will run its simulations. This work can require terabytes of hard-drive space (1 terabyte equals 1,000 gigabytes) for database storage, and immense computing power to perform the intricate calculations. Quality control, peer review, cooperation among research teams, and validation are all crucial for credible results. Scientists look for areas of consensus among scenarios produced by different models, and work to identify areas of uncertainty.

Scientists use climate change models to find correlations and trends, and to analyze future scenarios, varying degrees of temperature increase and other conditions. Computer models **can** forecast the likely effects of different scenarios, giving people the chance to compare outcomes. Computer models **cannot** predict specific events; too many chance happenings, such as fire starts by lightning or people, are involved. Models will never become "fortunetellers."

MAPSS also produces what scientists call "spatially explicit" results—maps. The first maps showed potential forests and other ecosystems for current conditions. Next the team used MAPSS to redraw the maps, by using changed climate scenarios and research findings about how trees respond to these changes (see sidebar above). The so-called "greenhouse gases" (carbon dioxide, methane, nitrous oxide, and others) are increasing. The increased levels of these gases may be driving general climate warming, with warmer temperatures and more precipitation, conditions that can be ideal for plant growth.

The expansion of juniper woodlands and ingrowth of other species into ponderosa pine forests likely have a strong climate signal.

"Climate change shows up in forests first as changes in growth," says team leader Ron Neilson, bioclimatologist. Under warming climate scenarios, interior Western forests would likely have more precipitation, but it would fall mainly in the traditional October-April wet season. Summers would still be hot and dry, and may be even hotter and longer than they are now.

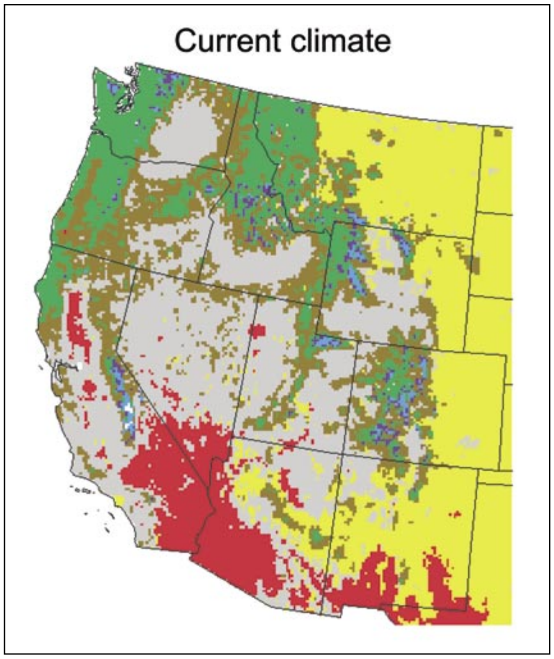
The MAPSS result for one future climate scenario shows a massive increase in woody vegetation across the Western United States, with expanded woody areas in eastern Oregon, many parts of the Great Basin, and other parts of the West. Many deserts in New Mexico, Arizona, and southeastern California would turn to grasslands. In Pacific Northwest coniferous forests, the broadleaf component would increase. In mountain ranges across the country, most forest zones would shift upslope, and subalpine and alpine life zones could be eliminated. In interior West mountain ranges, low-elevation forests now limited by aridity could expand into grasslands as precipitation increased. (See maps on next page.) Other ecosystem models may produce different results.

MAPSS simulations were used in national and global assessments of global climate change. The team modeled vegetation changes and led the analysis for North American forests in major federal reports on climate change. They also modeled global vegetation change for the intergovernmental panel on climate change (IPCC), part of the United Nations.

What we're seeing in the Western United States, team members point out, matches MAPSS results. The expansion of juniper woodlands and ingrowth of other species into ponderosa pine forests likely have a strong climate signal, and may not be due to fire suppression alone.

The second way that climate change shows up in forests is through changes in disturbance regimes—the long-term patterns of fire, drought, insects, and diseases that are basic to forest development. To find this connection, the team had to transform MAPSS into a dynamic model.

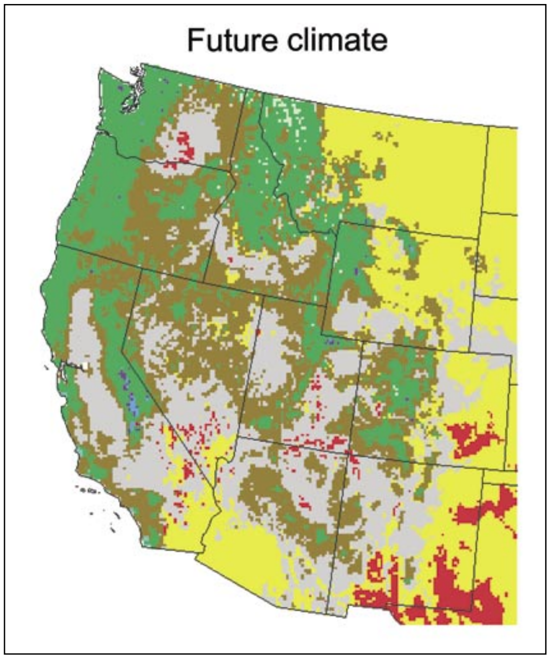
"Our steady-state MAPSS model could show scenarios for different conditions," Neilson explains, "but it didn't show how ecosystems would get there." A dynamic model would be more like the real world.

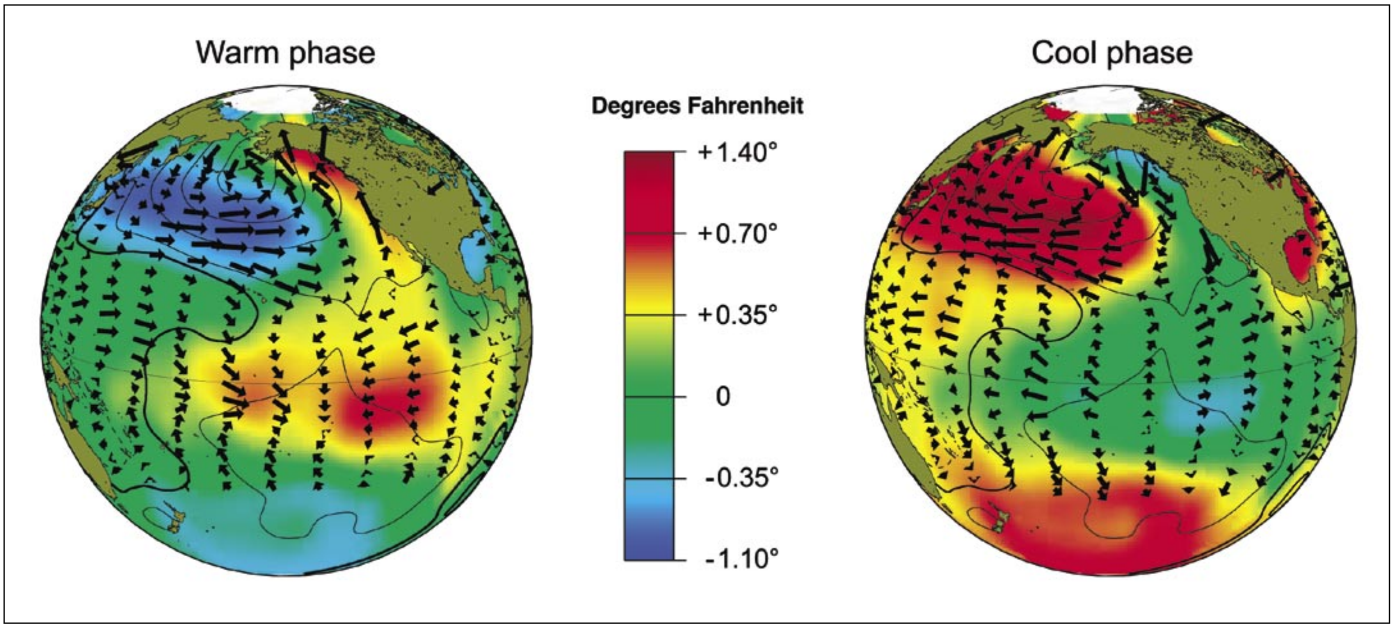


The MAPSS map on the left shows vegetation types that would grow naturally in the Western United States, under current climate, if there were no agriculture or cities. The MAPSS map on the right simulates potential vegetation distributions under the future climate scenario produced by the Canadian Global Coupled Model (CGCM1), with about 12 °F warming and a 22 percent increase in precipitation.

Principal vegetation types shown are:

green—coniferous forest
tan—savanna/woodland
gray—shrub/woodland
yellow—grasslands
red—arid lands.





The Pacific decadal oscillation, http://jisao.washington.edu/pdo

The Pacific decadal oscillation (PDO) is a long-lived pattern of sea surface temperature variability in the Pacific Ocean. The arrows and temperatures are the deviations from normal, with arrows representing wind deviations at the ocean surface. Ocean current deviations tend to be in the same direction as the winds.

How can scientists tell that climate variations are related to fire regimes?

The team's first dynamic model, MC1, used data simulated by climate models that included data from oceans and the atmosphere along with associated time lags and feedback loops. "Ocean surface temperatures are a key driver of climate," says Neilson. The Pacific, Arctic, and North Atlantic Oceans all have shifts in their surface temperatures, and all three influence climate regimes over the conterminous United States.

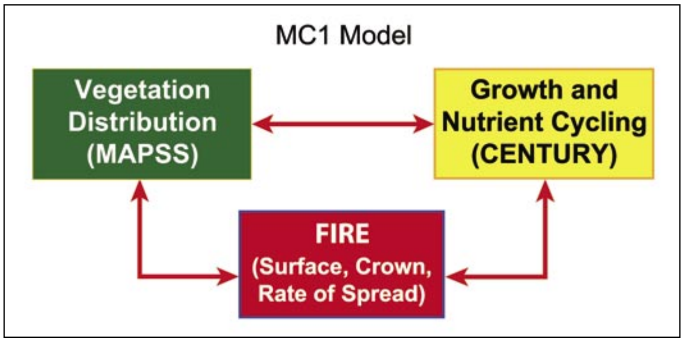
"The Pacific, however, is the largest ocean by far, and it has the most effect on climate," says Neilson. The Pacific decadal oscillation (PDO) is an index of sea surface temperature shifts, and the PDO has changed phase every few decades since people have been able to measure it. And, Neilson points out, "The climate regime shifts match beautifully with the PDO shifts."

An oceanic regime shift in the mid-1970s was a major influence on the climate regime shift that brought a period of wet years to Western states. These wet years encouraged the woody expansion in the interior West. The Pacific Ocean temperature records show a "hiccup" in 1988–89 when the PDO plunged into its "cool" phase for 2 years, in the middle of a two-decade-long "warm" phase. The Arctic and Atlantic Oceans also changed phases in 1988–89, but their changes have persisted. Since the 1988–89 changes, U.S. climate has swung through an El Niño wet period and back to a deep drought from 2000 to 2003.

"Any time there's a switch in climate regimes, it produces a pulse of extreme events, whether droughts, fires, or floods," continues Neilson. After the switch, the new climate regime still has yearly oscillations.

The heat source affecting ocean surface temperatures is the atmosphere, so more carbon dioxide in the atmosphere means warmer ocean surfaces. Also, with rapidly increasing global temperatures, climate variability may increase, causing cool decades along with warm ones.

Fire also plays an enormous role in changing ecosystems. To include the influence of fire, the team combined the MAPSS model with CENTURY, a biogeochemical model produced by a team at Colorado State University. Dominique Bachelet, biogeochemist on the team, explains that the combined MC1 model is able to simulate carbon, nutrient, and water cycles within ecosystems. It uses the data generated by climate models and then simulates the vegetation response. An attached fire model simulates the impacts of fire on ecosystem processes.



In the fully interactive MC1 model, all three boxes shown are "talking" to each other. MC1 is unique among vegetation models because it simulates fire over broad scales, and it changes plant distribution, growth, and nutrient cycling in response to simulated climate changes. These dynamics come closer to simulating real-world complexity.

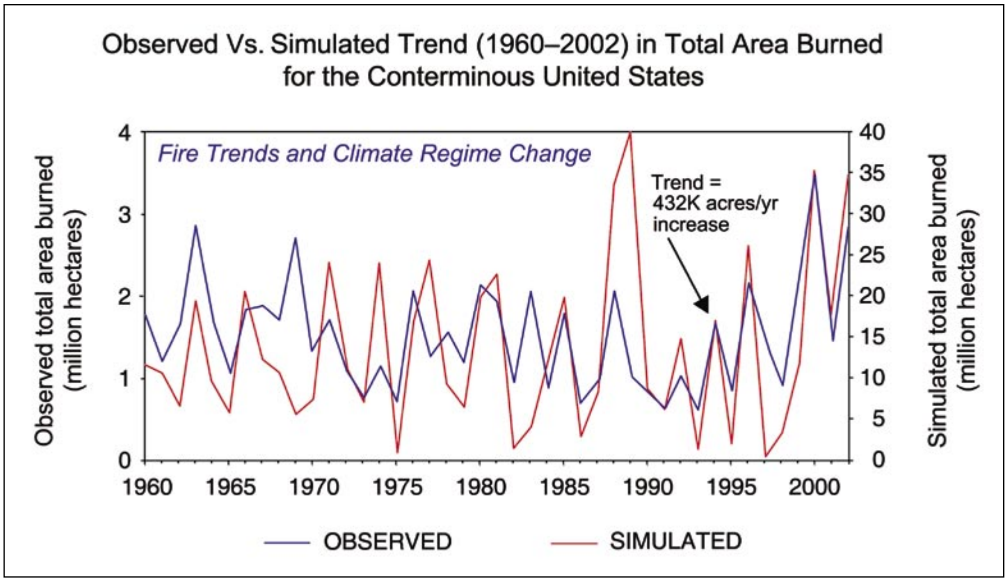
MC1 includes the growth, productivity, and decomposition dynamics that go on in ecosystems.

"After the model simulates a fire," says Lenihan, "it goes back into the growth and nutrient part of the model."

The model's first validation was a test against historical records. MC1 was given no information on the fires that had occurred in the 20th century and did not have fire suppression as a factor, but only climate information, including comprehensive weather data from 1895.

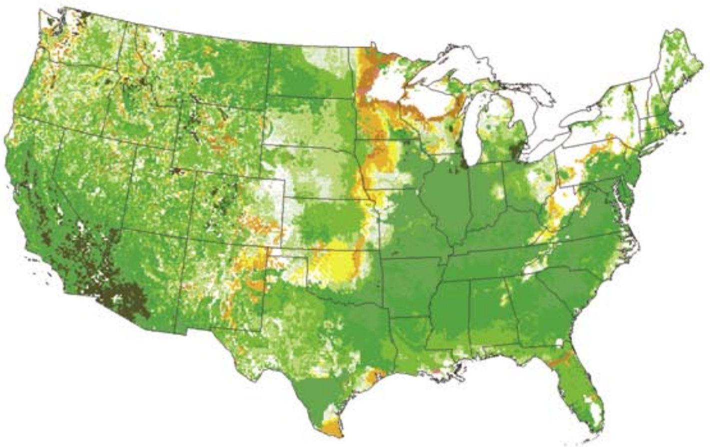
"MC1 accurately simulated the fire pulses of the last 100 years, with the big fires in the same areas as actually occurred," says Neilson. "It simulated the 1910 fires in Idaho, and it nailed Yellowstone in 1988. It was in the ballpark on the Tillamook Burn of the 1930s and a year early on the Biscuit Fire in southwest Oregon, which actually burned in 2002."

Thus MC1 was able to simulate 20th-century fire pulses, regions, and timing in the conterminous United States, based on climate signals alone. The major discrepancy was that the model showed burned areas about 10 times the acres actually burned. Lower actual burned acreage was likely due in large part to fire suppression.

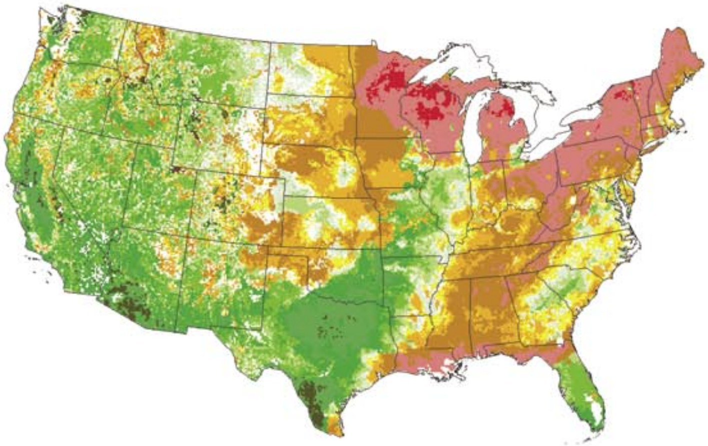


This graph shows the fire trends that MC1 simulated over the conterminous United States for a 40-year period (red line) based on climate information alone, with no fire suppression or fire ignition data. Simulated trends closely matched actual fire pulses (blue line) but at a much greater magnitude.

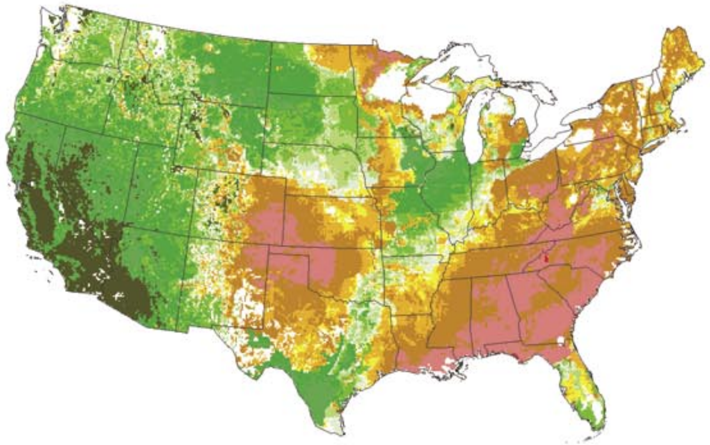
Vegetation Density Changes Under Potential Future Warming (MAPSS Simulations)



Small warming (5 °F, 22% increase in precipitation): The biosphere greens up; a sink for carbon (negative feedback).



Modest warming (7.5 °F, 18% increase in precipitation): Drought regions expand into previously greening regions. Carbon balance is near a threshold.



Considerable warming (9 °F, 22% increase in precipitation): Drought regions expand more. The biosphere becomes a source of carbon (positive feedback).

In six of seven scenarios, the West gets wetter, fostering woody expansion and increase of fuels. Colors show simulated changes in vegetation density for three climate change scenarios. Greens show increasing vegetation density, and tans-oranges-reds show decreasing density. In the conterminous United States, ecosystems might "green up" or increase in vegetation density under low levels of global warming, as shown in the top scenario. With considerable global warming, ecosystems may "brown down" or decrease in vegetation density in the East and much of the Great Plains, but the West could continue to get wetter, as shown in the bottom scenario.

The test against the historical record was a tremendous validation of the MC1 model. MC1's forecast for the next 100 years, then, might be of great interest.

Juniper woodlands now cover over 5 million acres in eastern Oregon, compared to less than half a million acres in 1936. Climate change likely would expand the range of some tree species but decrease the area covered by others.

What does MC1 forecast for the 21st century?

MC1 is now producing the first national-scale simulations of ecosystem and fire regime changes in the 21st century under various climate scenarios. The model uses actual climate data from 1895 to today. For simulated future climate data, the scientists use outputs from climate forecasting models.

"When we run the models for 100 years out into the future, we get woody expansion in the West and increased fire," says Neilson. "In six of seven future scenarios run through MAPSS, the West gets wetter throughout the 21st century, and woody and grass fuels increase." (See maps of three scenarios on previous page.) MC1, the dynamic model, has been run for two of the seven scenarios and results are comparable with the results from MAPSS, the equilibrium model.

In six of seven future scenarios, the West gets wetter throughout the 21st century, and Western summers would be hotter than now.

Although the West would be wetter, Western summers would be hotter than now. With more fuels available, in occasional dry years fires would burn both more area and more biomass than in even recent severe fire seasons. Fire risk could also increase significantly in Eastern U.S. forests if climate gets hot and dry enough, but farms, roads, and cities likely would block fire spread and reduce the actual acres burned from the catastrophic potential.

Under most climate warming scenarios, background fire levels would increase over most of the West. Fire levels would decrease only on the west side of the Pacific Northwest, where fuels would likely increase but forests would be wet enough that fire levels would change little.

In the interior West, dry forest and woodland communities, such as ponderosa pine forests and juniper communities, would likely cover more area than now. Climate suitable for Douglas-fir would extend to new areas, meaning that Douglas-fir might expand its range farther eastward from the Cascade Range and Sierra Nevada Range, and northward along the western Canadian coast into Alaska. "Simulation results show potentially suitable habitat," adds Neilson. "The model doesn't take into account species' actual seed dispersal abilities and people's land uses."

The hottest scenarios would occur if greenhouse gases, mainly carbon dioxide and methane, reached particularly high levels in the Earth's atmosphere. The more carbon that could be stored in solid form—all life forms living or dead contain carbon—the less climate warming would occur.

Is carbon storage in forests a possible way to slow global warming?

Enhanced carbon storage in ecosystems is, in fact, a major goal of the federal program to address climate change. But another forest policy is to reduce fuels and thus fire risk in the West, a policy that can release stored carbon. This key observation links the fire and fuels issue in the West to the global carbon change issue. The two issues are fundamentally coupled, yet the proposed solutions are seemingly opposed.

Carbon moves continually between solid and gaseous states. "Global ecosystems breathe carbon in during the summer, as plants grow. They breathe out in the winter, when decomposition exceeds growth," explains Neilson. "On average, 60 gigatons of carbon go into the air each year as ecosystems release carbon into the atmosphere. About 62.5 gigatons of carbon are pulled out of the atmosphere when the global ecosystem 'breathes in.' " The 2.5 excess gigatons of carbon "breathed in" are stored as new growth in trees and other plants, in essence stored as structured carbon, a process known as "sequestration."

"Our research suggests there is a threshold temperature, below which the biosphere greens up and stores carbon, but above which the biosphere becomes a source of carbon through drought, dieback, and fires, essentially a browndown."

Carbon sequestration in forests is currently a major component in international negotiations to limit greenhouse gas emissions. "But we need to understand the natural changes in the carbon budget before we can figure out if sequestration policies would be effective," comments Neilson.

The MAPSS team members use their models to study cumulative carbon change in U.S. ecosystems (simulating them as unmanaged ecosystems). Through most of the 20th century, simulated U.S. ecosystems were a net source of carbon to the atmosphere. But with a 1977 climate regime shift, the MC1 model suggests that natural U.S. ecosystems became a net carbon sink, owing to forest growth and woody expansion in the West. In addition, forests growing back on old farmland in the East are sequestering carbon. (This finding covers only carbon cycles in ecosystems, not car and factory emissions.)

In the Western United States, the conundrum would be how to balance carbon storage with reducing fuels and fire risk.

Fire Risk Forecasting, One Year at a Time

MC1 forecast potential for large fires in southwest Oregon in 2002. The Biscuit Fire, started by lightning in July, burned about 500,000 acres in the area.

In some ways, it's easier to forecast climate for a century than it is to forecast for 1, 2, or 5 years, timespans affected by El Niño–La Niña oscillations. "Although we had originally developed MC1 for long-term simulations," says Neilson, "we thought that with its fire component, it was technically sound to use for near-term forecasting."

The National Fire Plan funded the team's research into near-term fire risk forecasting. MC1 uses huge climate databases, with actual observed climate data covering the whole country from 1895 to the present. Climate databases are brought up to date each month.

For near-term forecasts, the team uses 6-month weather forecasts produced by three global climate models. Each climate model is built on different assumptions, but all three take into account fully dynamic oceans, including current sea surface temperatures and short-term anomalies such as El Niño. The three models then forecast global climate over the next 6 to 7 months, each model using its own set of rules and algorithms. Because the climate models also use different formats and measures, Ray Drapek, MAPSS modeler and geographic information systems scientist on the team, must convert these data into suitable formats for MC1.

"Since MC1 is not 'smart' enough yet to know that fires need ignition sources, I program the model with rules that trigger fires," explains Lenihan.

With all the preparation work done, the team runs the three climate forecast scenarios through MC1. The results are the first national-scale, high-resolution forecasts of fire risks in the United States that incorporate climate-driven year-to-year changes in fuel loadings and moisture characteristics. "Areas of consensus are evident under all three scenarios," remarks Neilson, "and this indicates a higher probability of accuracy."

MC1 produces 3- to 7-month forecasts of possible fire risks for the conterminous United States. In 2002, one of the worst fire seasons in decades, the model accurately predicted the fire susceptibility in the Southwest early in the season and extreme fire hazard in the Pacific Northwest later in the season.

For 2003, the model forecast that large fires could occur in southernmost Arizona, where in fact the disastrous Aspen Fire burned across nearly 85,000 acres and destroyed 333 homes and structures. It also forecast large fires in northern Montana, which occurred, including a fire in Glacier National Park that caused an evacuation of the park. MC1 forecast the approximate location of the B & B complex fires in Oregon and it forecast fires in southern California. However, because the model does not yet incorporate Santa Ana winds, it did not forecast the severity and extent of the late-season wildfire disaster in southern California.

"We're pushing the envelope in using the long-term climate models to produce near-term fire risk forecasting," comments Lenihan. By comparing actual events to their forecasts, the team sees where the model needs improvement.

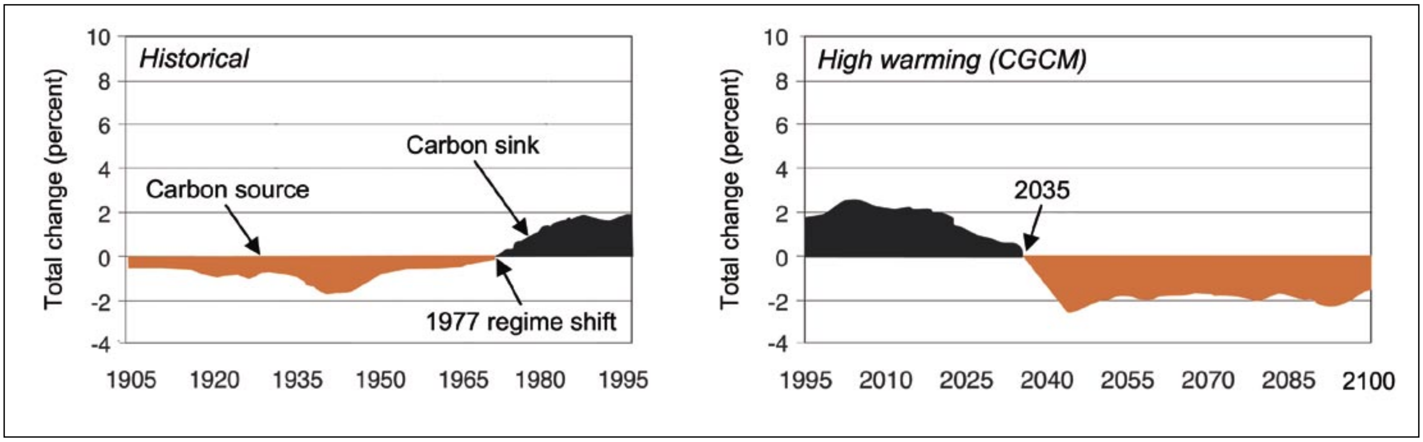
Currently they are building virtual bridges between MC1 and forest growth and yield models. More complete databases of actual fuels on the ground would be useful, and links to insect and disease simulations and land-use databases could be added in the future. Changing the grid cells to a smaller scale than currently used could mean a hundredfold increase in the data volume, but would enable forecasting for Western basin and range geography.

The accuracy of 2002 and 2003 forecasts has validated the model's approach, suggesting it can eventually be a useful planning tool for fire managers. But, the team cautions, the model should still be considered experimental. "Right now, we're barely comfortable going out 7 months with our forecasts," cautions Neilson.

Simulations for the 21st century project that for the next several decades, U.S. ecosystems would sequester so much carbon that even with increased fires, more carbon would be stored than would be burned off with fire. "Our research suggests there is a threshold temperature, below which the biosphere greens up and stores carbon, but above which the biosphere becomes a source of carbon through drought, dieback, and fires, essentially a browndown. If this occurs," says Neilson, "the biosphere in the United States would shift from net carbon storage to net carbon release, largely due to forest dieback in the Eastern United States." MC1 forecasts that point would be reached about mid-21st century under very warm scenarios, and much later in the century under other scenarios.

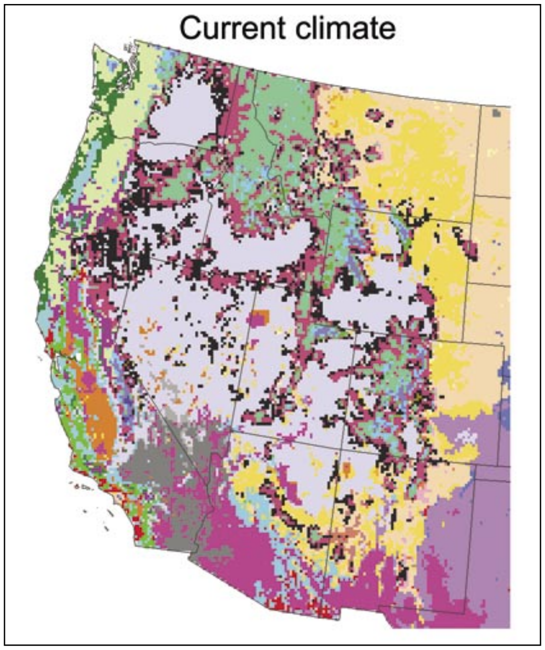
Two ways exist to limit the amount of carbon in the atmosphere, and thus reduce global warming. One way is to limit carbon dioxide emissions generated from burning fossil fuels.

The second way is to sequester more carbon in ecosystems or bury it in geologic structures. In the Western United States, however, the conundrum would be how to balance carbon storage with reducing fuels and fire risk.



Ecosystems in the United States released more carbon than they stored until about 1977. Since 1977, ecosystems have been a net sink of carbon, owing mainly to forest growth. Under a high warming scenario (Canadian Global Coupled Model), the ecosystems would become a net source of carbon to the atmosphere again about 2035, owing to drought and fire.

Prescribed burning reduces fire hazard—but releases carbon gases into the atmosphere. Balancing the carbon budget may become a consideration in forest management.



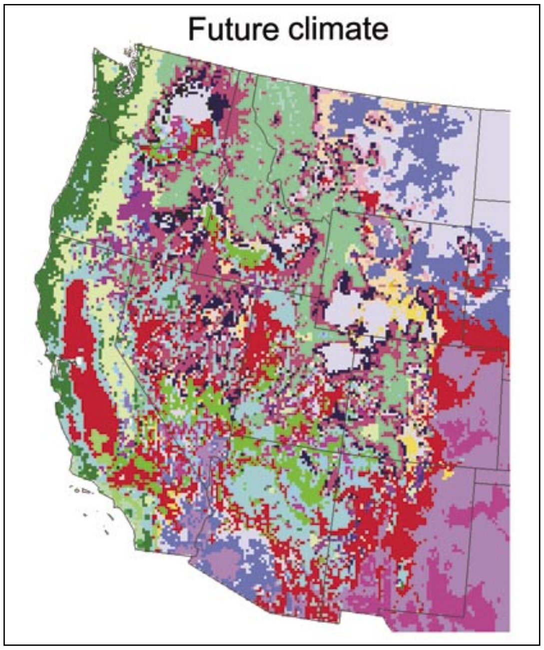
Under a high warming scenario, the extensive sagebrush areas of the interior West could be replaced by many types of ecosystems. On the two maps:

gray—sagebrush shrub-steppe ecosystems (which currently cover extensive areas)

greens—forest and woodland types

black and maroon—ponderosa pine savannas and juniper woodlands

other colors—other forest, shrub, and grassland types.



How could forest managers respond to large-scale climate change?

A district ranger cannot control climate influences on forests. He or she can, however, manage forests with climate influences in mind. Some key issues are:

Fuels in the wildland-urban interface. When people and communities are threatened by fires, it makes little difference whether climate or past fire suppression caused the hazard. "Most likely, managers would still want to reduce fuels in the wildland-urban interface," comments Neilson.

Forest resilience to climate change. Resource managers routinely make decisions to change forest structure for a number of reasons. New reasons might include managing forests to be more resilient to drought, long hot summers, and insect and disease outbreaks. The anticipation of possible climate changes might affect decisions on which tree species to plant.

Balance of carbon storage and fuel management. Balancing the carbon budget may become a management consideration. Neilson lists some options. "If you burn fuels to reduce fire risk, you pump carbon into the atmosphere. If you use the wood as biofuels, you can offset some use of fossil fuels. If you can treat fuels in a way that keeps carbon stored, such as wood products, you can increase the carbon stored."

"Reducing wildfire risk and storing carbon seem to be in conflict with each other," Neilson points out, "challenging managers to find ways to do both."

What thresholds might we cross in the future?

To ecologists, a threshold is the point at which an ecosystem switches from one response to another, such as the greenup-to-browndown scenario. Neilson describes other thresholds that may be reached if the simulations are accurate.

"The Southeastern United States appears to be among the most sensitive regions in the world to increasing temperatures. It could convert from forest to savanna or grassland through drought, insect infestation, and massive fire."

"Once a certain temperature threshold is reached in the Great Basin, species may move northward rapidly and ecosystems might change quickly. The sagebrush ecosystem could be reduced from millions of acres to isolated areas in southwest Wyoming, eastern Washington, and a few other pockets. If this occurs, it would probably be disastrous for the sage grouse and some other species, but beneficial for others. The extensive sagebrush areas of the interior West would be replaced with many types of forests and woodlands."

"We can try to enforce the ecological status quo, which will be increasingly difficult. We can sit back and let change happen. Or, we can manage for change."

Neilson adds, "We may need to rethink what ecosystems in the interior West will look like. Reducing fuels to pre-European settlement levels may be a misplaced goal. We would be trying to restore against a strong climate signal, like trying to push the tide back out into the ocean."

Even the best models can offer only best-science simulations. The world, and nature, are full of surprises. Neilson acknowledges the uncertainty.

"We have three options. We can try to enforce the ecological status quo, which will be increasingly difficult. We can sit back and let change happen. Or, we can manage for change."

For Further Reading

Note: The September 2001 issue of *BioScience* Vol. 51(9) is a special issue with articles on the forest sector analysis of the national assessment of the potential consequences of climate variability and change.

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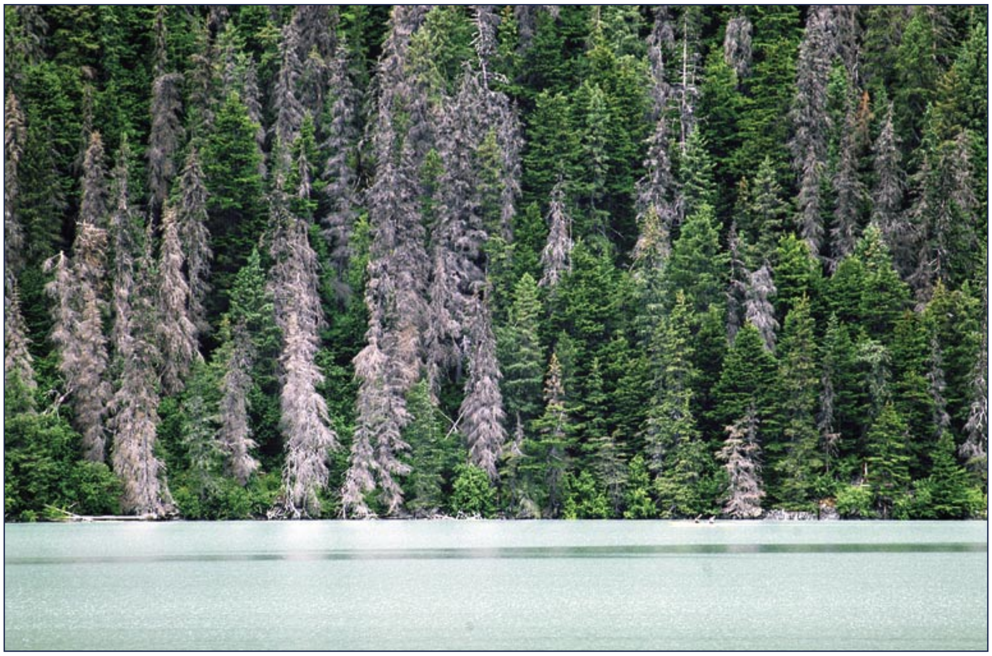
Bachelet, D. [et al.]. 2001. Climate change effects on vegetation distribution and carbon budget in the United States. Ecosystems. 4: 164–185.

Duncan, S. 1999. More rain, more drought: Will the forests thrive or die? Science Findings 14. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 6 p.

Duncan, S. 2002. Is carbon storage enough? Can plants adapt? New questions in climate change research. Science Findings 44. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 6 p.

Joyce, L. [et al.]. 2001. Potential consequences of climate variability and change for the forests of the United States. In: National Assessment Synthesis Team, eds., Climate change impacts on the United States – foundation report. Cambridge, United Kingdom: Cambridge University Press: 489–521. Chapter 17.



Climate fluctuations have cascading effects on forests. On Alaska's Kenai Peninsula, an area loved by anglers, kayakers, and hikers, years of drought and warmer temperatures led to a spruce bark beetle outbreak that killed millions of spruce trees.

Resources on the Web

U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Mapped atmosphere-plant-soil system (MAPSS). http://www.fs.fed.us/pnw/corvallis/mdr/mapss. (1 October 2003).

U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Dynamic vegetation models. http://www.fs.fed.us/pnw/corvallis/mdr/mapss/dynamic. (1 October 2003).

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