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Climate Change Tipping Points: A Point of No Return?

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Climate Change Tipping Points:
A Point of No Return?

Summer 2012 saw records fall for intensity of drought and number, size, and cost of wildfires in the Central and Western United States, and the climate forecast calls for more of the same in the near and distant future. When wildfire breaks out, emergency responders decide their immediate strategy based on past experience and quick judgment calls. But in the long term, land managers need to plan for a warmer climate on a time scale of decades, or even a century or more, to better reflect the life span of trees and forests. Studies supported by the Joint Fire Science Program (JFSP) are beginning to provide this type of guidance for managers.

A central question of interest to researchers is whether there are tipping points, points of no return beyond which landscapes will not revert to their historically documented conditions. Can managers' actions postpone or halt these drastic changes in forest conditions, or will they instead be forced to plan for a response to inevitable, abrupt changes in the landscape?

Tipping Points in Western Forests Present Managers with Multiple Challenges

The Bureau of Land Management, National Park Service, U.S. Fish and Wildlife Service, and U.S. Forest Service have all acknowledged the need to plan for a warming climate and have published documents outlining their approach to managing the lands they oversee in response to climate change. These major federal agencies acknowledge the judgment of the United Nations Intergovernmental Panel on Climate Change (IPCC) that there are two approaches to dealing with climate change: adaptation and mitigation. Mitigation aims at postponing or reducing effects of climate change on the landscape, while adaptation requires responding to the inevitable change in ways that continue to support healthy landscapes for people, plants, and animals.

Mitigation efforts include active interventions, such as managing vegetative species known to provide long-term storage of carbon or using prescribed fire to lessen the risk of uncharacteristically severe wildfire. At some point, however, the mitigation approach might not prove sufficient to postpone the cumulative effects of change, and adaptation will be required. This would be the case, for instance, when a forest can no longer regenerate naturally after fire, and shrub or grassland species begin to dominate the landscape.

To plan its response, the U.S. Forest Service, in its "National Roadmap for Responding to Climate Change" (2010), stresses the need for scientific research on which to base its planning process. A primary role for scientists in addressing climate change will be to identify the associated knowledge gaps and fill them. As knowledge increases and uncertainty recedes, policies can be formulated and refined to better address climate change.

Each of the federal land management agencies has similar goals. In addition, the agencies recognize the need for partnerships in responding to the challenges and communicating with the public on the issues.

Tipping Points in the Greater Yellowstone Ecosystem

The subalpine forests of the Greater Yellowstone Ecosystem (GYE) historically experienced a long fire-return interval of 100 years or more, and when fires happened, they tended to be severe. This was the case during the 1988 fires in Yellowstone National Park. "Severe fire is a natural part of the ecosystem, and the forest in the GYE was ready for a large fire," says Erica Smithwick, assistant professor of geography at Pennsylvania State University. Though this event was within the range of the historic variability in terms of severity, "people were alarmed," she says.

Mike Ryan

Yellowstone National Park after the 1988 fires. Stand-replacing fires are part of the natural history of lodgepole pine and are considered normal.

Smithwick's team wanted to predict the probable occurrence and consequences of more frequent fires in the GYE as the climate continues to warm (JFSP Project No. 09-3-01-47). They used down-scaled global climate models (see sidebar, Modeling Climate Change) to project change for 100 years in the future, though the highest degree of confidence in the model's projections is confined to the mid-21st century. For that timeframe, using a range of climate warming scenarios from three global climate models, the team assumed spring and summer temperature increases ranging from 4-6º C and a shortening of the fire-return interval to about 30-50 years.

This degree of warming could severely affect the ability of the lodgepole pine forest to rebound from fire. Historically, regeneration of lodgepole pine after a stand-replacing fire has not been a problem; the tree's serotinous cones actually require fire to release the seeds. However, it takes 15-20 years for the tree to reach reproductive maturity. More frequent fire could compromise the forest's ability to regenerate, sending it on the path to becoming a grassland or savanna. "We may have to tell managers that these systems in the future may not be the same as in the past," she says. "There may be several fires on the order of the 1988 fires in the next 50 years."

Since one approach of mitigation is to manage forests to maximize their potential as carbon sinks, Smithwick's team specifically projected the probable transition of the GYE from a carbon sink to a carbon source. The goal of mitigation could become more elusive in the future if these high-elevation lodgepole pine forests cease to store as much carbon as current forests. In addition, changes in fire-return intervals in this ecosystem might trigger a tipping point beyond which these forests are converted into a different landscape altogether.

If such drastic changes do occur, managers could be forced to take the path of adaptation. With a shortened fire-return interval, the landscape could undergo dramatic change from forest to savanna. Aboveground carbon stocks of grasslands and woodlands are lower than in forests. Although belowground carbon stocks can be large in these ecosystems, it can take centuries to millennia for these to develop. Thus, over management timeframes, such vegetation transitions would reduce carbon stocks.

"We have to manage for the capacity of systems to recover and the flexibility of systems to change," says Smithwick. One approach could be to plant trees that are adapted to a shorter fire regime, such as ponderosa pine, but Smithwick cautions that this is not an option to consider lightly. On the other hand, if aggressive management steps are not taken, and the landscape does change to more open grassland, this conversion might benefit grazing animals including elk and bison. "These decisions can present a great quandary, but we need to be open to a landscape that is temporally and spatially variable."

Erica Smithwick

Lodgepole pine tree recovery 15 years after the 1988 Yellowstone National Park fires.

In addition, the rate of change might be even more drastic than the study predicts. The researchers originally used the A2 scenario from the IPCC "Special Report on Emissions Scenarios" (2000), one of the more high-end estimates of greenhouse gas emissions. Since the publication of that report, actual emissions have exceeded the estimates, so the temperature increases projected by the A2 scenario are considered conservative.

An earlier study by co-investigator Michael Ryan had presented a more positive picture of the future. Using a more conservative climate scenario, Ryan, an emeritus scientist with the Rocky Mountain Research Station and a senior research scientist with the Natural Resource Ecology Laboratory at Colorado State University, studied a chronosequence of 77 stands of lodgepole pine in Yellowstone National Park and modeled how they would change under future climate scenarios (JFSP Project No. 03-1-1-06). His study evaluated net carbon storage after fire and found that carbon stores would reach equilibrium fairly quickly after fire compared to their historic fire-return interval.

"I was more optimistic back in 2008," says Ryan, but further studies convinced him future fires are projected to occur much more frequently than the historical record. "We appear to already be shifting to a fire-return interval of less than 30 years." It takes lodgepole pine 70-100 years to recover enough biomass to make up for the loss of carbon and nitrogen after fire. With a shorter fire-return interval, the lodgepole pine forest could cease to serve as a carbon sink.

In some forests, such as ponderosa pine, which is adapted to a more frequent fire-return interval, thinning and prescribed fire are a management option. "If we lose a little carbon by thinning, overall, the forest will be more resilient," says Ryan. This strategy will not work for lodgepole pine, however. "Lodgepole pine doesn't stand thinning very well, and it has a thin bark that doesn't handle prescribed burning." A better approach in this ecosystem might be to create fire breaks around the landscape. "Thinning on the large scale just doesn't work in this type of forest," he says. "You need strategic fire beaks around what you are interested in saving."

Long-Term Stress in Coniferous Forests

Chronic stress to trees can arise from the increased temperatures and drought characteristic of a warming climate. Over time, this stress might lead to higher rates of mortality and increase the trees' vulnerability to fire, insects, and diseases. Since changes to mortality patterns can tip an ecosystem to something completely different—trees die faster than new recruits can grow—understanding the factors that lead to tree mortality is imperative.

The mechanisms that lead to tree mortality, however, are poorly understood. "We don't understand what kills trees. We don't know the processes at a physiological level, how drought stress interacts with fire damage and insect attack," says Phil van Mantgem, a research ecologist with the U.S. Geological Survey's Western Ecological Research Center at the Redwood Field Station.

To determine whether warm, dry conditions will increase the probability of trees dying after a fire, van Mantgem used monitoring data collected from prescribed burns between 1982 and 2004 (JFSP Project No. 09-3-01-68). The information was gathered from more than 250 forest plots in units subjected to prescribed burning in coniferous forests across the Western U.S., including California, the Southwest, and the Rockies. Most of the plots were in ponderosa pine and white fir forests with a fairly frequent fire-return interval prior to fire exclusion. Historically, these forests typically experienced slow, creeping fires, "but with current fuel accumulations they have a higher likelihood of burning catastrophically," says van Mantgem.

National Park Service

Sugar pine survival is at risk in the presence of more frequent fires since the species takes 30-40 years to reach reproductive maturity.

The data were gathered primarily through the extensive fire effects monitoring program led by the National Park Service, which has been collecting field data on fire effects in a consistent manner across the U.S. for several years. A similar approach was taken by the national Fire and Fire Surrogate Study, which also provided data for the project (JFSP Project No. 99-S-01). Long-term data are critical to answering key questions about climate change and forecasting future conditions. "It's a soap box of mine," van Mantgem says. "Long-term records are invaluable, and they become more valuable the longer they exist." Modern tools such as remote sensing are very powerful, but don't tell the whole story. "They can't tell you what is going on beneath the canopy." Direct field measurements, though expensive to collect, are vital to a deeper understanding of the long-term effects of fire and climate change.

The researchers found fire-caused tree mortality to be correlated with drought conditions, which are expected to intensify under climate change. Though this study did not forecast tipping points, it can be used to identify unknown or underappreciated factors that could lead to irreversible changes in the health of a forest ecosystem. "In this and related work, we get signals that there might be chronic stressors currently affecting forests in the West," van Mantgem says. These chronic stressors could make the forests less resilient to future changes in climate.

Species of Special Concern

A second part of van Mantgem's study focuses on one particular tree of concern, the sugar pine. If a tree can be described as charismatic, *Pinus lambertiana* would be a prime candidate. Nineteenth century naturalist John Muir called the sugar pine—the tallest of the pine species—the "king of the conifers." In the late 20th and early 21st centuries, however, conditions are not stacking up well for this iconic tree. Fire exclusion has led to denser forests, crowding out light for this moderately shade intolerant tree. White pine blister rust, a fungal pathogen introduced to the United States at the turn of the last century and which affects all western five-needled conifers, is a threat to the species. In addition, the sugar pine takes 30-40 years to reach reproductive maturity, which puts its survival at risk in the presence of more frequent fires.

"For this one species, we are trying to understand the links between climate and growth and subsequent mortality." To that end, van Mantgem and colleagues tracked 30 years of tree growth, taking cores from tree trunks and measuring the width of the tree rings. Growth rate slows and tree rings shrink when the tree is stressed by drought. "If trees grow quickly, we've found they are less likely to die than trees that grow slowly," he says.

Data were collected before and after prescribed fire in summer 2002 at burn units located in Sequoia National Park, California, and on a Fire and Fire Surrogate Study site that had not experienced fire in more than 100 years. After accounting for the extent of crown scorch and stem char, researchers found that mortality from the prescribed fire was greater in trees with slow growth, particularly for those trees that did not die immediately after the fire (delayed mortality). "We had a good, detailed measure of growth trends using the tools of tree ring analysis, not just the short-term patterns, but going back in time to look at long-term patterns of growth," van Mantgem says. "The best models of postfire mortality were partially based on those growth records." In light of observed and predicted long-term climate warming and drying, managers might need to take a more cautionary approach to prescribed fire in ecological niches of special concern such as the remaining sugar pine stands.

Long-Term Restoration Strategy for a Pine-Oak Forest

Since 1995, the Bureau of Land Management, Ecological Restoration Institute at Northern Arizona University (NAU), and Arizona Game and Fish Department have been restoring the pine-oak forest ecosystem in the Grand Canyon-Parashant National Monument, west of the Grand Canyon National Park in Arizona. The Mount Trumbull Ponderosa Pine Ecosystem Restoration Project uses thinning and burning to reconstruct the openness and fire characteristics natural to this ecosystem.

Because of the wealth of data already collected in this ecosystem, NAU graduate student Corinne Diggins, NAU School of Forestry professor Peter Z. Fulé, and colleagues found this site well suited for a study examining how thinning and prescribed fire management strategies might need to be altered given projected climate change (JFSP Project No. 06-3-3-05). "Forest treatments do not always turn out exactly as planned, which is why a real example may be a better starting point for modeling than a simulated treatment," Fulé writes in the JFSP final report.

In addition, a major mission of the Grand Canyon-Parashant National Monument, jointly managed by the Bureau of Land Management and the National Park Service, is ecological restoration and continued support of restoration efforts. Managers from the two agencies, therefore, wanted recommendations for a plan that can be implemented in the near future, including actions that will have measurable repercussions for the next 100 years.

Historically, this forest, which is dominated by ponderosa pine and Gambel oak, experienced a frequent fire-return interval, about every 5 years, which naturally thinned trees and left an open canopy with a diverse understory. This ecosystem was sustainable even in the presence of drought and fire. "We are trying to recapture that sustainability," says Fulé. "In the more crowded forest, fire now turns into crown fire."

The researchers combined historic data and modeling of future warming scenarios. A modified version of a forest simulation model, the widely used Forest Vegetation Simulator, was used to project

John P. Roccaforte

This photo shows the Mount Trumbull Ponderosa Pine Ecosystem Restoration Project in northwestern Arizona. The landscape in the foreground has been treated, whereas the landscape in the middle ground is untreated.

tree growth, total biomass, potential forest products, and carbon storage under three scenarios of climate change through 2108: no climate change relative to the historical record, a low to moderate increase in warming, and a higher warming scenario. The model projected forest response under several management scenarios, which included variations on treatment type (no action management, burning, thinning, or burning and thinning), fire season, fire frequency, and thinning intensity.

Considering that climate change alone will result in increased tree mortality, Fulé suggests that implementing burning at a level to minimize tree death is an important management strategy. Taking into account the lower productivity and higher mortality rates of trees in a regime of increased drought, the researchers determined that mimicking the historically short fire-return interval would negatively affect the forest. A longer interval, up to 20 years, would ensure benefits from fire, reduce expenses related to prescribed fire or tree thinning, and minimize the impacts of smoke in the region. Though sparsely populated, the area is not far from Grand Canyon National Park, which is designated a Class I area subject to the most stringent air quality standards.

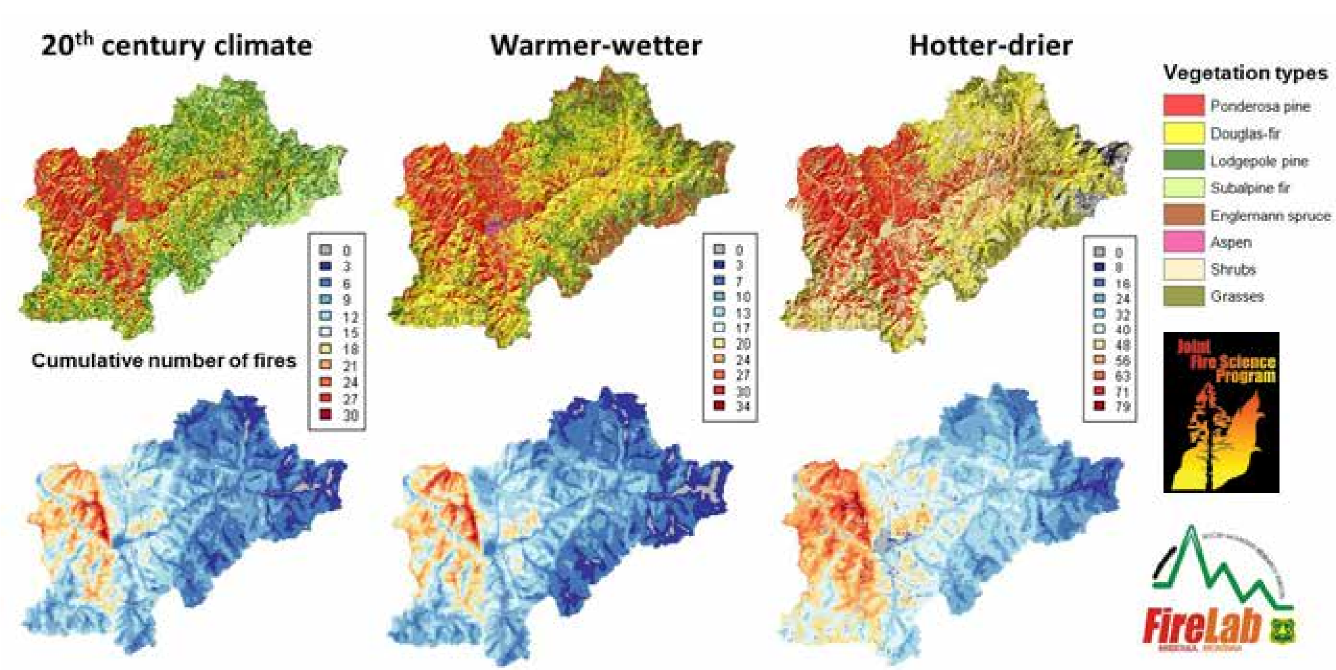
In addition to maintaining the health of the trees themselves, maintaining an open forest is also good for wildlife, including species of management concern such as the migratory Mexican spotted owl and the northern goshawk. Fulé says the restoration at Mt. Trumbull also benefits other species such as butterflies. “When you open up the forest, there are more diverse food sources, which is good for the butterfly larvae and adults, encouraging higher numbers and more species.”

The specific details of this study are most applicable to the Southwest, but the methods used might be helpful in other areas to determine how forests will respond to climate change and how to plan accordingly. “There is no perfect knowledge about how climate change will play out, so we need to be prepared to deal with that uncertainty and not be taken by surprise,” says Fulé.

Caution: Tipping Points Ahead

While global climate models are based on the best available science, there is still some uncertainty about what temperature and precipitation patterns are going to look like in the future in different regions. Researchers with the U.S. Forest Service Rocky Mountain Research Station’s Missoula Fire Sciences Laboratory have used a novel approach to examine the potential climate-induced changes of three different landscapes in the Western U.S. (JFSP Project No. 09-3-01-17).

Rather than downscaling global climate model predictions for particular areas, they ran the FireBGCv2 landscape fire and vegetation model (see sidebar) with incremental shifts in temperature and precipitation, from warm, to hot and dry, to wet



Rachel Loehman

Climate-driven changes in vegetation types and fire regimes simulated using the FireBGCv2 model, East Fork of the Bitterroot River basin, Montana. Hotter, drier climate conditions result in a more than two-fold increase in the number of fires simulated on the landscape, as well as a change in forest species composition and an increase in grass- and shrubland.

future climates. Model results highlighted two key issues. First, projected climate changes might create inhospitable conditions for some tree species, leading to new forest types or structures in some landscapes. Second, increases in fire frequency or area burned—changes that happen under warmer, drier conditions—can catalyze changes in species composition or reduce forest cover altogether.

For all three landscapes, the researchers found that annual area burned increases as temperature increases, which will accelerate mortality for a variety of tree species. "Fire makes a huge difference on the landscape," says Rachel Loehman, a research scientist at the Missoula Fire Sciences Laboratory. "If and when they burn, in forests already affected by climate-related stressors like drought and mountain pine beetle epidemics, fires can cause a forested landscape to shift to a grassland or shrubland. This is especially true if fires burn differently than they have in the past—more frequently, with higher severity, or covering more area—because the forests may not be adapted to these emerging fire regimes."

. . . some landscapes are more resilient to climate changes than others.

These findings hold true even for scenarios with increased precipitation. While increased precipitation can offset increases in temperature, when temperatures increase by 5-6° C, increases in moisture don't buffer the effects of warmer temperatures. "If you have more precipitation with warmer temperatures, that doesn't mean there will be more water available for plants," says Loehman, because temperature increases lead to higher rates of evapotranspiration in plants. Moreover, at some point, changes due solely to gradual temperature increases could lead to a tipping point. When combined with amplified fire activity, Loehman adds, "abrupt and long-term changes could occur on the order of days to months."

The researchers found that each landscape they studied responded differently to changes in temperature and precipitation and thus had different tipping points. Each of the study sites—McDonald watershed of Glacier National Park, Montana; Central Plateau of Yellowstone National Park, Wyoming; and East Fork of the Bitterroot River basin, Montana—has forests with differing forest types and structures, elevations, fire-return intervals, adaptations to fire, and predicted future climates. The Glacier and Yellowstone National Parks, for example, have forest species less adapted to frequent fire and warming temperatures than the East Fork of the Bitterroot River basin. Due to these differences, the researchers found that some landscapes are more resilient to climate changes than others.

The condition of the East Fork of the Bitterroot River basin is perhaps less dire than for the other landscapes. First, it is dominated by forests of fire-adapted ponderosa pine. It also has a surface fire regime and historically smaller and more frequent fires and can resist change better than others in a warmer and drier environment. "A ponderosa pine ecosystem can be more resilient to climate shifts and increased fire activity because it is a dry, fire-adapted landscape, so a tipping point may occur later than in other systems," says Loehman, "but fire exclusion—and the buildup of fuels that can lead to high-intensity, high-severity fires—will likely make even dry forests more vulnerable to abrupt and persistent change." Using prescribed fire to reduce fuel loads might be more effective and ecologically appropriate here than in some other landscapes. "Use of fire in a fire-adapted landscape is a sound tool for promoting desired structure and composition of current forests," she says.

Regardless of fire adaptations, older trees have some tools for resisting climate changes that younger trees don't, such as deep roots and thick layers of duff that retain moisture. "For seedlings, conditions are harsh; they have tiny, delicate roots and are less resistant to droughts and warming than older trees," Loehman says. Older trees can also survive fires that will kill small, young seedlings. Thus, warming temperatures and increased fire activity can present a double whammy to young forests. "After a stand-replacing fire, the new seedlings on the forest floor need time to grow above the height of flames in a subsequent fire and to produce seeds for the next generation of trees. If the forest reburns before this happens, it could delay establishment of a new forest for years or decades," says Loehman, "especially if forests are already stressed by drought."

Loehman says that the use of fire as a tool for landscape restoration is a good example of an area where forward-thinking management could achieve both mitigation and adaptation. "Fire will have a place on landscapes with more regularity," she says. "Wildfires are a reality, but on the other hand, we will likely manage for some level of suppression for the long haul. The topic we should start talking about is using fire to our advantage economically and ecologically, with mitigation and adaption in mind, making fire work to achieve long-term goals."

Warming in the Alaska Boreal Forest

Climate models predicting faster warming in the Arctic have already been confirmed by direct observation in Alaska. On the coast, entire villages are being relocated inland due to changes in seasonal sea ice dynamics. Thawing of the permafrost is leading to subsidence of the ground, and drier conditions have increased the risk of fire on the tundra. In addition, earlier snowmelt means less incoming energy from the sun is reflected back into the atmosphere, which multiplies the effects of a warming climate, says Paul Duffy, an environmental statistician with Neptune and Company, Inc., an environmental consulting firm.

"Some estimates show the Arctic is warming twice as fast as regions in the lower latitudes. High latitudes are undergoing rapid climate change that is arguably outside the range of historical variability," says Duffy, who participated in a JFSP study to refine a computer model used in boreal ecosystems to assist managers in planning for climate change and shifts in fire regimes in Alaska (JFSP Project No. 05-2-1-07). Given the rapid pace of climate-induced ecosystem changes in Alaska, managers are in desperate need of such tools.

Duffy and colleagues took a combined approach to forecast the response of the interior Alaskan boreal forest to climate change. The field component of the study used burn severity data collected from 392 plots across 10 sites in the boreal forest that burned in 2004, the largest fire year on record in Alaska. The team specifically wanted to know the effects of climate, stand age, forest structure and type, and slope and aspect on burn severity. The team found few significant differences across the sites, though the season of burn did matter on two of the sites. The information was used to develop the modeling component of the study.

"The boreal forest holds a tremendous amount of carbon, both aboveground in the trees and belowground in the soil."

The collected data was used to refine the Boreal ALFRESCO model, which was then used to forecast the effects of climate change on fire/climate interactions under six future climate scenarios based on global climate models from the IPCC. For all six future scenarios, the forecast for the next 50 years shows increased fire severity resulting in a change from mature spruce to deciduous species. "The Alaskan boreal forest is one of the simpler in terms of species composition, with black and white spruce being the dominant conifers and birch and aspen the common deciduous trees," says Duffy. "With a significant increase in fire severity, we could see conversion of a lot of conifer stands into deciduous types for many decades." The most immediate effects are predicted to occur dramatically and relatively soon, in the next 20 to 30 years, and could leave a patchy network of older spruce. This patchiness might, after a few decades, result in a decrease in extent and severity of fire, as deciduous forests tend to be less flammable.

In addition to the forecast landscape-scale changes, increased fire incidence and severity could produce a feedback effect, increasing emissions of carbon dioxide. "The boreal forest holds a tremendous amount of carbon, both aboveground in the trees and belowground in the soil," says Duffy. "Carbon dioxide levels in the atmosphere are higher than they have been in more than 450,000 years, and fire-initiated changes in the ecosystem above and belowground could release additional large amounts of carbon that will likely reinforce warming at the higher latitudes."

Duffy says the model results do not provide exact spatially explicit forecasts of ecosystem development for managers but instead can be a guideline for decisionmaking. "We provide managers with the state of the science to help inform their decisions, but the models do not dictate exactly what to do. The models should be used to help inform the complex decisionmaking process of land management."

D. Haggstrom, courtesy of SNAP and ACCAP

A smoke column develops during an experimental burn outside of Fairbanks, Alaska.

D. Haggstrom, courtesy of SNAP and ACCAP

Taken immediately after an experimental burn outside of Fairbanks, Alaska, this image shows the effects of fire inside and outside a fuels treatment plot.

Flexible Management

Recent fire patterns in the West confirm that warming is already causing changes in forested landscapes that are likely irreversible. Overall, the suite of JFSP studies on climate change and tipping points presents a number of strategies for adaptation to and mitigation of the effects of climate change, but the research also underscores that there is no one-size-fits-all approach.

Those responsible for the future of our forests and the functions they provide—be it recreation, wildlife habitat, commercial timber, or watershed benefits—struggle daily with management decisions, some immediate and dramatic, others requiring long-term strategies in an uncertain future. Judicious thinning and prescribed fire is a tried-and-true strategy that has been used for decades, though this approach will need to be fine-tuned in a warming climate. In some forests, it might be possible to work with the natural topography to limit the spread of fire. Strategic fire breaks can also help preserve remnants of the historically documented landscape. What strategies are most appropriate in different ecosystems? "We need to frame these issues so as to manage for the capacity of systems to recover while also incorporating the flexibility of systems to change," says Smithwick. "We may sometimes need to allow changes to occur in ways that can benefit ecosystems and people."

Suggested Reading

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Modeling Climate Change

In a suite of JFSP projects devoted to climate change and tipping points, several downscaled models and other tools, both traditional and novel, have been used to make predictions at environmentally and ecologically relevant scales.

Downscaling General Circulation Models

General circulation models, also known as global climate models, have been under development since the mid-20th century and constitute the basis on which global and regional climate change predictions are made. These models are constantly being refined, and as more data are gathered, scientists gain increased confidence in the ability of the models, both atmospheric and oceanic, to predict future climate.

From a practical standpoint, however, general circulation models are not designed to assess climate change at the fine resolution required to forecast conditions and make planning decisions at relevant scales (e.g., small geographic regions and specific ecological niches). At a finer scale, warming will have different effects depending on the response of specific vegetation and local topography, including elevation. In addition, warming will have different local or regional effects because of the influence of regional weather and climate patterns, such as the El Niño/Southern Oscillation and summer monsoons, which have a strong influence on precipitation patterns in the Western United States. The general models are, however, useful as drivers of downscaled modeling. “We can take a statistical look at the results of the coarser model and use those results to understand the probability of what is happening at the finer scale,” says Erica Smithwick, assistant professor of geography at Pennsylvania State University.

CENTURY

For their complementary studies on the Greater Yellowstone Ecosystem (GYE) and Yellowstone National Park, Smithwick and Michael Ryan used the CENTURY model. It is “a general model of plant-soil nutrient cycling which is being used to simulate carbon and nutrient dynamics for different types of ecosystems including grasslands, agricultural lands, forests, and savannas,” according to its website. “We used this model to predict carbon and nitrogen stocks following the recurrence of a 1988-type, severe fire in the GYE,” says Smithwick. The model was parameterized using Ryan’s data from a chronosequence of 77 stands of lodgepole pine. In his study, Ryan generated new allometric equations to predict biomass specific to the region. These equations are basically a way to estimate biomass and carbon from easily measured variables such as tree height or stem diameter. http://www.nrel.colostate.edu/projects/century/

Forest Vegetation Simulator

For a study on forest restoration treatments of ponderosa pine forests in the Southwest, researchers used a geographic and species-specific version of the Forest Vegetation Simulator (FVS), the Central Rockies variant focused on southwestern ponderosa pine. The FVS has been adopted and maintained by the U.S. Forest Service since the 1980s “as the national standard for forest growth and yield modeling,” according to the FVS website. This model has variants for 20 geographic regions across the United States. A recent addition to the suite of tools is Climate-FVS, a climate-sensitive version designed for the Western United States, with an eastern version under development. http://www.fs.fed.us/fmsc/fvs/whatis/index.shtml/

PRISM

It’s not always necessary to create new modeling tools to assist in predicting vegetation and fire responses to climate change. For their large-scale analysis of fire effects data on coniferous temperate forests in California, the Southwest, and the Rockies, Phil van Mantgem and colleagues used an existing climate mapping system, the Parameter-elevation Regressions on Independent Slopes Model (PRISM). PRISM is the official source of climate data for the U.S. Department of Agriculture.

The plots in this study lie in remote, mountainous regions without nearby weather stations. PRISM estimates temperature and rainfall data from instrumental observations, making adjustments for features such as elevation, aspect, slope, and rain shadows. This tool was used to calculate climatic water deficit, a biologically meaningful index of drought. This drought index appeared to correlate with postfire tree mortality.

In addition, rather than employing newly generated field data, the researchers used historic information on the effects of prescribed fire. An extensive database on surface fuels and individual tree damage and mortality from prescribed fire has been collected by the National Park Service since the 1980s and maintained by the interagency database management system FFI (FEAT/FIREMON Integrated). This is one of the first times these data have been used to look at broad-scale patterns of fire effects across the West. http://www.prism.oregonstate.edu/

Boreal ALFRESCO

The Boreal Alaska Frame-Based Ecosystem Code (ALFRESCO) is a fire management and planning model specific to wildland fires in the Alaskan subarctic and boreal vegetation. The model was initially developed by University of Alaska Fairbanks (UAF) researcher Terry Chapin and University of Minnesota professor emeritus Tony Starfield, with subsequent major revisions by UAF researcher Scott Rupp. Paul Duffy worked on the development of the fire-climate linkage as part of his dissertation at the UAF (JFSP Project No. 01-1-1-02).

Modeling Climate Change (continued)

ALFRESCO forecasts the response of vegetation to disturbances driven by climate and fire. The model is being improved by downscaling historical and future projection data. Eventually, the model's timeframe will be shortened from annual to monthly steps to better simulate seasonal variation. ALFRESCO also incorporates data from the National Land Cover Database for Alaska, one of 50 digital maps covering all the states, to characterize existing vegetation at a finer spatial resolution. Finer resolution of an Alaska vegetation grid allowed reclassification of areas considered to be tundra that were, in fact, black spruce. In addition, comparisons between the more recent ALFRESCO model and the older Vegetation Dynamics Development Tool revealed substantial differences between the two, indicating more fine tuning of both models is warranted.

Duffy cautions that all data is not created equal. "Satellites came into use for the purpose of mapping fires in the late 1980s and 90s, so practically speaking the historical fire data from the past decades are more accurate than those in the 1950s, when people flew around in planes with a map drawing fire perimeters," he says. http://www.frames.gov/rcs/7000/7132.html

FireBGCv2 Landscape Fire Succession Model
The FireBGCv2 process model (BGC stands for biogeochemical) is an ambitious undertaking to produce a spatial model capable of simulating complex ecological interactions across landscapes, to produce information on climate-fire dynamics and fire effects on vegetation composition, structure, and ecosystem attributes such as carbon, biomass, and hydrology.

"We are not modeling a linear system," says Rachel Loehman, who developed the model along with Rocky Mountain Research Station colleagues at the Missoula Fire Sciences Laboratory. This type of simulation platform is useful when detailed field studies on large landscapes and over long time periods are prohibitively expensive or when scientists explore effects of future climate changes on ecosystems.

In practical terms, this model is too complex to run on most desktop computers and is considered a tool for research rather than a model that managers can use for local-scale predictions. "It is not realistic for a manager to run this model," Loehman says. "We provide the results and communicate the information back to managers, who can also give us feedback. That communication and transfer of scientific information is the role of the JFSP, to make that bridge between research-oriented results and practical management decisions." http://www.firelab.org/research-projects/fire-ecology/139-firebgc

An issue of concern for managers is to know whether and how models should be used in ecosystems apparently similar in terms of vegetation and climate to those for which the tools were created. Smithwick cautions that there is uncertainty about applying one model tailored to a specific location to another ecosystem, no matter how similar different ecosystems might seem in terms of vegetation and climate. "The question is to what degree managers can use this discordance of results and adapt the models to a specific location," she says.

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