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Striving for Long-term Forest Sustainability—Even as the Climate Changes

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Joint Fire Science Program

Fire Science Brief

RESEARCH SUPPORTING SOUND DECISIONS

To achieve long-term forest management in the ponderosa pine forests of northwestern Arizona, managers must consider the influence of climate change. Credit: Pete Fulé.

Striving for Long-term Forest Sustainability—Even as the Climate Changes

Summary

Climate change, and its ecological impact, is right on the horizon. According to climate predictions over the next century, the southwestern United States will face higher temperatures and greater evaporative loss, which will heighten the possibility for severe drought. The stress of more frequent, intense droughts can increase tree mortality, hinder growth, and alter forest structure and composition. As a result, it's now more important than ever for land managers to understand how today's decisions and actions can impact future forest conditions. To develop answers, researchers conducted a study in the oldest ponderosa pine restoration project in the Southwest. Located in northwestern Arizona, the Mt. Trumbull ecological restoration site offered a perfect opportunity for researchers to use a realistic landscape example to compare treatment methods and schedules for long-term maintenance of forest restoration treatments. The specific study objective was to use a forest simulation model—both in its standard form and with modifications to account for climate change effects—to forecast changes in tree structure, biomass, carbon, and potential forest products under alternative treatment scenarios.

Key Findings

- Among the various climate, thinning and fire management, and regeneration scenarios, future forest structure varied in consistent ways:
  - Simulated effects of warming climate reduced forest density,
  - No-action management consistently resulted in the most dense forests, while prescribed burning resulted in the least dense forests, and
  - Scenarios that increased the number of strong regeneration events from 1 to 2 years per century had higher tree densities, but basal areas were not necessarily greater.
- Biomass changes paralleled changes in basal area, with climate, fire treatment, and regeneration scenarios having the greatest effects.
- Carbon naturally followed the same trends as total biomass, with different climate and treatment scenarios resulting in an astonishingly large range in aboveground carbon stocks after 100 years, from a high near 64.4 tons per acre to a low of 4.7 tons per acre.
- Modeling predictions suggest that although future climate conditions will be warmer, drier, and more likely to burn, fuel production will decline, thus creating an eventual tradeoff between increased opportunities for severe fire to burn, but less fuel being produced.

Changes ahead

Growing evidence suggests that climate change is on the horizon. In the southwestern United States, climate predictions indicate higher temperatures and less moisture over the next century, resulting in a greater potential for severe drought. The stress of severe drought can then alter forest structure and composition, thwart growth, and increase tree mortality.

Forest managers are treating or proposing to treat millions of acres of forests to reduce fuels and to restore ecosystem processes. Through ecological restoration, managers aim to recapture the natural resilience of an ecosystem's structure, function, and composition. For dry ponderosa pine (*Pinus ponderosa*) forests, this typically involves reinstating the frequent surface fire regime and restoring the landscape to include open forests of large trees and productive, diverse communities of grasses and flowering plants. "Ecological restoration is often focused on whole ecosystems, trying to restore conditions that will perpetuate a sustainable forest into the future," said Pete Fulé, principal investigator.

It is critical for land managers to understand how today's management actions may affect long-term forest conditions—and to determine how to best maintain these forests as the climate changes. To help gain this understanding, researchers conducted a study at the Mt. Trumbull restoration site in northwestern Arizona. Specific study goals included using a forest simulation model to predict tree growth for 100 years under different climate and management scenarios and estimating changes in forest structure, biomass, carbon, and wood removed under those scenarios. After completion of the simulation part of the study, researchers planned to use the information obtained to compare management alternatives and to provide guidance on sustaining this landscape going forward.

Ecological restoration efforts at Mt. Trumbull give vegetation and flowering plants such as this lupine a second chance to thrive. Credit: Ecological Restoration Institute.

A tangible example

The Mt. Trumbull restoration site is known as the largest long-standing ponderosa pine restoration project in the Southwest. The area covers more than 2,965 acres between the ancient volcanoes of Mt. Trumbull and Mt. Logan in the Uinkaret Mountains in the Grand Canyon-Parashant National Monument. Soils here have a basaltic parent material and the dominant vegetation type is ponderosa pine and oak (*Quercus gambelii*) forest. Other tree species include New Mexican locust (*Robinia neomexicana*), Utah juniper (*Juniperus osteosperma*), and pinyon pine (*Pinus edulis*).

A well-monitored, designated research site, Mt. Trumbull has helped provide much-needed landscape-scale data on the effects of forest restoration on vegetation, wildlife, and fire hazard. Pre-treatment measurements in this area were first taken in 1995. Mt. Trumbull was chosen for this study not only because of its rich dataset, but because it has forest management projects completed on the ground. “This was one of the goals of the research: to use a real project landscape, rather than a hypothetical or model-simulated example,” stated Fulé.

Between 1995 and 1997 and prior to the implementation of restoration treatments on Mt. Trumbull, 116 plots were established on a 984-foot grid. Of those plots, 55 were designated as control, or untreated, and 61 were treated. In 2003, measurements of tree attributes such as species, diameter at breast height (dbh), height, crown base height, and condition were conducted. The 2003 measurements supported an analysis of treatment effects on fire behavior and assessment of an ecological restoration landscape experiment as well as the project covered here.

For the simulation modeling portion of the study, researchers used the Forest Vegetation Simulator (FVS) to forecast future stand conditions under different climate, regeneration, and management scenarios. An individual tree growth and yield statistical model, the FVS is widely available and frequently used across agencies to predict forest growth and yield. It is a highly precise model of ponderosa pine growth, but because it is a statistical model based on past forest growth measurements, it does not directly simulate fluctuating environmental conditions such as climate change. However, for this study, researchers modified the standard FVS model to simulate predicted climate change effects.

Model simulations were projected in 10-year increments for 100 years into the future (2008–2108) using the Central Rockies/Southwestern Ponderosa Pine variant of FVS. The maximum stand density index when ponderosa pine composed 81–100 percent of the stand was 514 trees per acre, assuming trees of 10 inches dbh.

Mt. Trumbull study areas included a treated forest landscape (foreground) and an untreated control landscape (background). Credit: J.P. Roccaforte.

To develop realistic management scenarios for conservation of the restored attributes of forest structure and fire regime in the Mt. Trumbull area, researchers met with land managers from the Bureau of Land Management and National Park Service. The management scenarios used during the simulation portion of the study included:

- No-action management, including a no-action control area (no restoration treatment, no other actions) and a no-action treated area (single restoration treatment, without additional thinning or burning). “No-action” was the base model to which the other treatments were compared and it was the only management scenario considered for the control area.
- Prescribed burning with fire return intervals of 5, 10, or 20 years.
- Prescribed burning during different seasons, including spring, summer, and fall. Each seasonal simulation was run with a fire return interval of 10 years.
- Thinning of ponderosa pine.
- Prescribed burning and thinning, with the treated area representing two thin-from-below treatments (thin 40 percent of basal area and thin 60 percent of basal area) and with prescribed burning every 10 years.

For the FVS portion of the study, a variety of simulation conditions were used. See the following table.

Climate Effects	Description
No Climate	No effect of climate = maintenance of historical climate
Climate Low	BAI* decline and 15% increase in modeled mortality
Climate High	BAI decline and 30% increase in modeled mortality
Regeneration	**Description**
Regen Low	Regeneration added at start of simulation
Regen High	Regeneration added at 1st and 50th year of simulation
Management Treatments	**Description**
Control	Dense forest with no treatment at start or throughout simulation
Treated	Restoration thinning + burning at start, no further treatment
Burn 5 Yr	Restoration followed by 5-yr repeated prescribed burning
Burn 10 Yr	Restoration followed by 10-yr repeated prescribed burning
Burn 20 Yr	Restoration followed by 20-yr repeated prescribed burning
Burn Spring	Restoration, 10-yr repeated prescribed burning, spring weather
Burn Summer	Restoration, 10-yr repeated prescribed burning, summer weather
Burn Fall	Restoration, 10-yr repeated prescribed burning, fall weather
Thin 40%	Restoration, thin 2x from below, cut 40% of pine basal area
Thin 60%	Restoration, thin 2x from below, cut 60% of pine basal area
Burn Thin 40%	Thin 40% plus prescribed burning
Burn Thin 60%	Thin 60% plus prescribed burning

* BAI* = basal area increment.

To determine biomass, researchers selected local species-specific aboveground biomass formulas for each tree species, except New Mexican locust, as models for this species were not available. Biomass models varied and may have included calculations for stem wood, stem bark, total twigs, live and dead branches, foliage, and whole tree. Carbon measurements represented 48 percent of the total biomass.

Simulation results

Forest structure

Over the 100-year simulation period created in FVS, climate scenarios had the greatest impact on the sustainability of treatments. Under the most severe condition, or climate high, only four of the 12 management scenarios ended the simulation with basal area within the broad target range, which was 28.7 to 101.5 ft^2 per acre. Seven scenarios had very open forests, below 28.7 ft^2 per acre, and only the no-action control exceeded the target range. However, even the no-action control simulation indicated a 51 percent decline in basal area over 100 years.

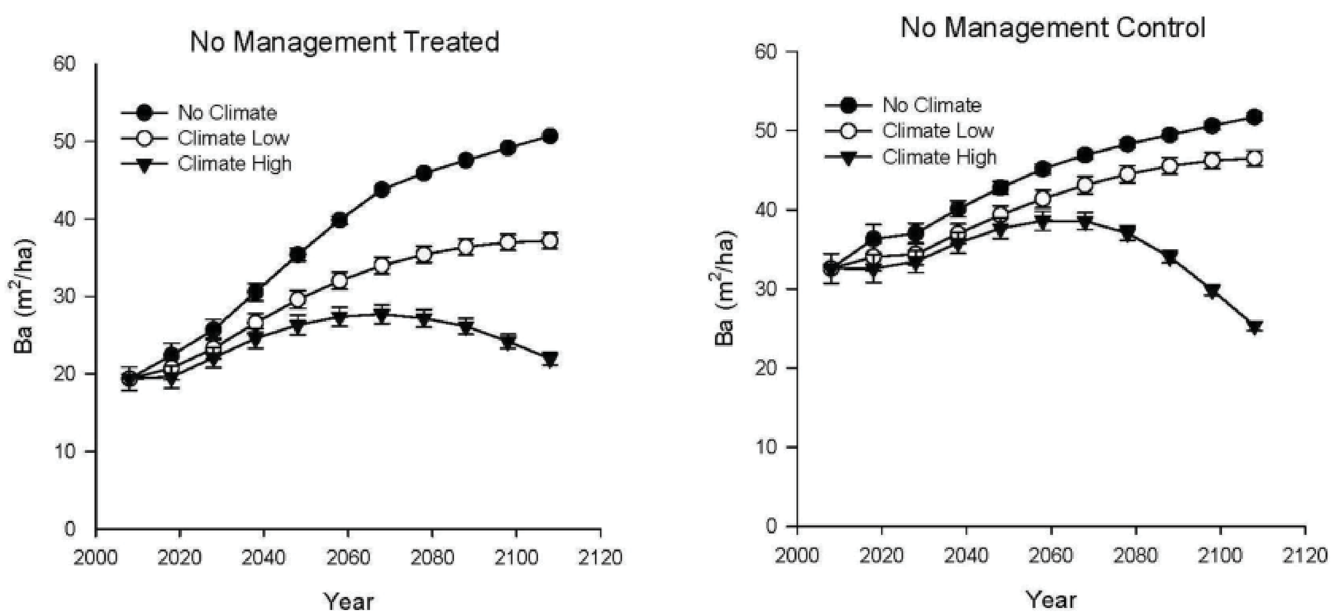
"The decline in basal area in our modeling basically means that the forest is thinning out because of high death rates. This is the model reflecting the observation that tree mortality increases during drought," said Fulé. Simulation results also indicated that future forest structure varied in similar ways among the different scenarios. For example, simulated effects of warming climate consistently reduced forest density. The densest forests were typically the result of no-action while the least dense forests were the result of prescribed burning (in any treatment combination). In addition, high regeneration scenarios had higher tree densities than low regeneration scenarios, however, basal areas were not necessarily higher.

Thinning treatments alone had almost a negligible impact, with basal area and other forest structural characteristics that were virtually identical to the no-action treatments. Between prescribed burning alone and the prescribed burning/thinning combination, there was also almost no difference, indicating that the treatment effects were due primarily to fire. Burn season had little impact on the simulation results, but burn frequency had a substantial effect. Specifically, (1) repeated burning is important to maintain the effects of the restoration treatment, keeping forests open and resistant to severe burning, but (2) the best choice of the specific burn frequency to use varied depending on the climate scenario.

Although it has been widely predicted that future climate conditions will support warmer, drier fuels, longer fire seasons, and more burning, the modeling conducted in this study suggests that fuel production will decline because trees will grow more slowly and die more readily, so there will eventually be a tradeoff between increased fire and less fuel. On this, Fulé stated, "The idea that fire hazard might decrease in the future as forest growth slows was surprising. A common observation about the recent past is that fire hazards are increasing because warming climate is associated with longer fire seasons and drier conditions. This is true and only likely to get worse in the future. However, our modeling suggests that the future forest will also grow more slowly. Over the long term (decades to century), this means that the increased chance of fire due to long, dry fire seasons might be balanced against the reduced amount of fuel (vegetation) in the forest." The replacement of the current vegetation by different species, not modeled in this study, is another potential future outcome.

Biomass, carbon, and wood

According to simulation results, biomass changes paralleled changes in basal area, with climate, treatment, and regeneration scenarios having the greatest effects. In both the control and treated areas, biomass reached high



No-action management in both the control (left) and treated (right) sites led to unsustainably high forest density over the 100-year simulation period. However, under simulated "high" climate change, forest density declined substantially.

levels, revealing that a lack of management practices could quickly reverse the effects of the original restoration treatments. Under increasingly severe climate change, however, biomass was reduced by as much as 58 percent in the no-action scenarios compared to the standard model. Furthermore, in scenarios where prescribed fire was not used, oak, pinyon, and juniper biomass was higher. Carbon measurements naturally followed the same trends as total biomass, with a vast range in aboveground carbon stocks after 100 years, from approximately 4.7 tons per acre to 64.4 tons per acre.

The amount of wood harvested also changed during the simulation, regeneration, and climate scenarios. Since there were restrictions on the types of species thinned (ponderosa pine only), and tree dbh (maximum 8 inches), the number of thinned trees varied widely, ranging from as few as 1 to over 1,269 pine trees per acre. Additionally, thinning treatments appeared to have little influence on total basal area. Ponderosa pine volume also fluctuated, ranging from approximately 27,150 ft^3 per acre to over 90,000 ft^3 per acre in 2048, and a broader range of 10,000 to 125,800 ft^3 per acre in 2098. Sawn wood products did not vary consistently with thinned volume and revenues from thinned products ranged from approximately $17 to $73 per acre for wood cut in 2048 and up to a maximum of $259 per acre for wood cut in 2048 under the highest regeneration condition.

Managing a moving target

For forest managers, it's important to consider that the climate is changing. It's equally as important to understand how those changes may affect the existing and future landscape, and how management strategies must be altered to reduce tree mortality and wildfire potential and severity. Fulé said, "The big picture is that the best strategic actions to achieve long-term management goals must be considered in light of climate change effects. The most appropriate actions under present conditions may no longer be optimal in the future. Simulation modeling does not provide perfect answers but can help managers explore the range of options to come up with flexible and durable management strategies."

Recommendations

Researchers recommend using frequent surface fires to mimic the historical fire regime and to maintain the existing restored forest structure under current climate conditions. Compared to repeated thinning or thinning and burning, repeated burning may be the most effective tool to achieve long-term sustainability.

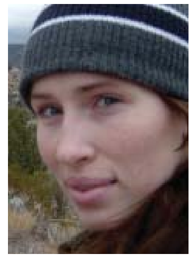
To help reduce tree mortality under warmer climate conditions, the best management strategy may be to increase fire intervals from 5 years (the historical average fire return interval in this forest) to 20 years. In addition, management efforts may need to be altered across sites with elevational gradients. As a result, researchers recommend prioritizing restoration management in mid- to high-elevation zones, with secondary management efforts in low-elevation ecotones, where sustaining current vegetation types is less likely to succeed in the face of climate change.

Further Information: Publications and Web Resources

Diggins, C., P.Z. Fulé, J.P. Kaye, and W.W. Covington. 2010. Future climate affects management strategies for maintaining forest restoration treatments. *International Journal of Wildland Fire*. 19: 903–913.

Fulé, P.Z. and D.C. Laughlin. February 2007. Wildland fire effects on forest structure over an altitudinal gradient. Grand Canyon National Park. *Journal of Applied Ecology*, 44. p. 136-146. http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2664.2006.01254.x/abstract

Scientist Profiles



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