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PNW Pacific Northwest Research Station

# Science FINDINGS

## INSIDE



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*"Science affects the way we think together."*
Lewis Thomas

# Crowded and Thirsty: Fire Exclusion Leads to Greater Drought Sensitivity in Mixed-Conifer Forests

Andrew Merschel

*A densely stocked stand in the Deschutes National Forest. After a century of wildfire suppression, the crowded trees compete for water and nutrients. The resulting stress leaves them more susceptible to drought, insect outbreaks, and disease.*


## IN SUMMARY

*Wildfires were a frequent source of disturbance in forests of the Western United States prior to Euro-American settlement. Following a series of catastrophic wildfires in the Northern Rockies in 1910, the U.S. Forest Service adopted a broad wildfire suppression policy that has resulted in forests thick with small trees. These crowded trees compete for nutrients and water and experience increased drought stress in summer.*

*In recent decades, many trees have died following drought, bark beetle outbreaks, and severe wildfire. A link between this mortality and increasing susceptibility to drought was suspected, but a direct connection hadn't been confirmed. To learn more, researchers with the USDA Forest Service Pacific Northwest Research Station and Oregon State University used a stable carbon isotope approach to test how individual trees in a mixed-conifer forest in the Deschutes National Forest responded to the exclusion of wildfire.*

*Their analyses revealed that trees had become more drought stressed, and stands that had a basal area greater than 100 square feet per acre in 1910 are more drought stressed today. Conversely, stands that were less densely stocked in 1910 still exhibit signs of drought resistance and are thus less susceptible to insects and pathogens. These findings are critical for land managers when deciding how and where to allocate resources for forest restoration in dry mixed-conifer forests to mitigate the effects of drought.*


*"Men love to wonder, and that is the seed of science."*
—Ralph Waldo Emerson

In 2014, the Deschutes Collaborative Forest Project approached Andrew Merschel, a faculty research assistant at Oregon State University, with a research proposal: could he reconstruct the historical wildfire regime in the Deschutes National Forest? Specifically, the collaborative was interested in an area southwest of Bend, Oregon, that represented a transition between lower elevation dry ponderosa pine forests and higher elevation moist mountain hemlock–grand fir forests.

The collaborative had previously worked with Merschel and Tom Spies, a research forester with the Pacific Northwest (PNW) Research Station. In 2010, Spies led a project to inventory forest conditions across the Deschutes National Forest to develop a better understanding of how mixed-conifer and ponderosa pine forests were affected by fire suppression and logging during the 20$^{th}$ century. This project became the backbone of Merschel's master's degree program and helped the collaborative develop a better understanding of variation in restoration needs across forest types. However, the collaborative also needed to know how frequently fire was occurring across a range of forest types prior to the 20$^{th}$ century, and how past fires affected forest composition and structure. Because Merschel was eager to expand historical records further back in time, he welcomed the opportunity.

"The collaborative's previous project areas were in the drier areas on the national forest, and they were moving into relatively moist dry forests in the new project areas," Merschel says. "They were concerned with how they were going to write management plans and agree on what treatments to do there."

Since 1910, wildfire had been excluded from the Deschutes National Forest and other wildfire-adapted landscapes in the Western United States by the U.S. Forest Service's wildfire suppression policy. The impetus for the policy was a rare series of catastrophic wildfires in northern Idaho and western Montana that collectively became known as the "Big Blowup." These wildfires resulted in 3 million acres burned in 2 days and at least 85 deaths. The new policy made fire suppression a priority across forest types in the Western United States, regardless of how frequently they burned historically.

In the subsequent century, with the removal of frequent low-severity wildfires that historically maintained open fire-resistant forests, forest susceptibility to drought, insects, and disease changed dramatically. In many areas, stands are now overcrowded, which results in trees becoming stressed by limited water and nutrient availability. Thousands of acres are filled with dead and dying trees as a result of defoliating insects, root pathogens, and bark beetle outbreaks that cover more acres than were observed historically. Most of these insects and diseases are native to the West, but they affect more trees today because there has been an increase in host species, including Douglas-fir and grand fir. Densely packed trees increase disease transmission, and stressed trees have few defensive resources. Additionally, epidemic levels of mortality from bark beetles and defoliating insects occur more frequently now than prior to 1910.

To restore these fire-adapted landscapes, the U.S. Forest Service, state and other federal agencies, tribes, and nonprofit organizations are reintroducing wildfire through prescribed burning, or allowing naturally caused wildfires to burn when they pose little risk to communities. The questions that forest managers need answers to are "How often should areas burn and where should the fires burn?" Merschel's wildfire reconstruction provides some useful help.

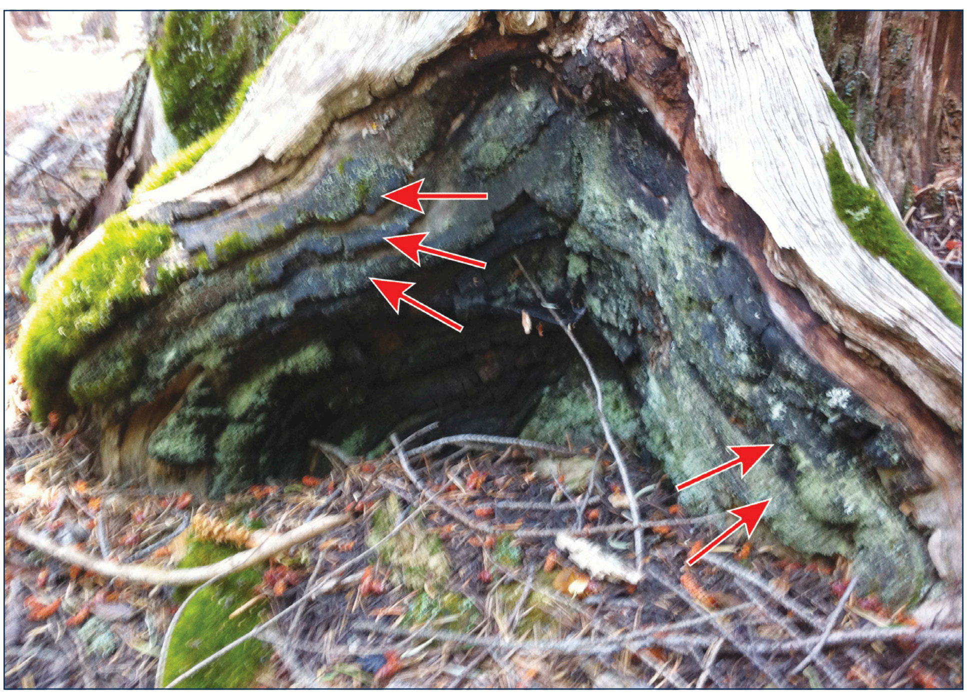
For the rest of 2014 and into 2015, Merschel and a team of field assistants installed 105 plots across nearly 25,000 acres. On each plot, 27 trees were selected for sampling: cross-sections were taken from fire-scarred trees and cores from live trees. These tree cores and cross-sections were cross-dated to determine each tree's age and the years historical wildfires occurred. From a dataset of 2,907 live trees and 418 fire-scarred trees, Merschel constructed the historical wildfire history of the study area.

In 2016, Merschel delivered the results to the collaborative. Among his findings, within the 25,000 acres, severe fires were small and rare, while low-severity fires were frequent

## KEY FINDINGS

- A lack of wildfire has reduced drought resistance in mixed-conifer forests and made them more susceptible to insects, pathogens, and other disturbances.
- Based on tree-ring stable carbon isotope analyses, drought stress has increased in stands with a basal area greater than 100 square feet per acre in 1910 when fire suppression was enacted.
- Stands with a basal area less than 100 square feet per acre in 1910 were initially buffered from increased drought stress and benefited from rising ambient concentrations of carbon dioxide ($CO_2$), resulting in increased photosynthesis. However, temporal trends in tree-ring carbon isotopes indicated that photosynthesis of old-growth ponderosa pine has decreased by 10 percent since 1830, compared to expected trends resulting from increasing atmospheric $CO_2$.

Andrew Merschel



*Fire scars on a tree burned by low-severity fire at roughly 15-year intervals. The fires did not kill the tree, but each resulted in a fire scar, providing a record of the event. The scars are stacked on top of each other and look like folds.*


*Purpose of PNW Science Findings*

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Andrew Merschel

*Forest structure influences forest resilience to disturbance. The old-growth forest on the left experienced multiple low-severity fires over time and the large widely spaced trees were resistant to the 2012 Pole Creek Fire. The (former) forest on the right was a dense plantation of young trees with interlocking crowns that developed without fire or thinning. Fuel abundance, continuity, and a lack of large fire-resistant trees resulted in severe or stand-replacing fire.*

and burned extensively throughout the forests, even in moist grand fir forests. Topography also played a role in how wildfires spread.

Over the course of the research project, Merschel and Spies had many conversations about the project, but in one conversation in particular they discussed wildfire suppression in the context of trees and drought. How had the trees responded to the absence of wildfire? Had the trees become drought stressed or less drought resistant because of the overcrowded forests? They hypothesized that the answer was likely to be yes.

"The story of fire exclusion, changing of the density, and increasing the competition among drought-sensitive species is consistent across the West," Merschel explains. "If the changes in fire frequency and changes in forest density were that dramatic, there should be some sort of signal in tree growth or in the tree rings."

Frederick Meinzer, a research ecologist with the PNW Research Station and a colleague of Spies, was brought into the discussion and proposed a solution. "Tree ring data can tell you the growth trends over the year, but to actually drill down into the mechanisms behind that growth, you need more information," he says. "That's where the stable isotope approach comes in."

Merschel and Spies welcomed the opportunity to collaborate with Meinzer along this new line of research. "We could add tree stress to the historical picture and that would help us get a better sense of how trees respond to drought and lack of fire," says Spies.

With funding available through the PNW Research Station and Oregon State University cooperative research program, the study was approved. Meinzer tasked Steven Voelker, now an assistant research professor at the State University of New York College of Environmental Science and Forestry, to lead the carbon isotope analysis.

When Voelker learned of the drought resistance question Merschel and Spies sought to answer, he understood the need to find a direct link. "They could make the argument, based upon other unaffiliated studies, that the trees in the Deschutes National Forest are becoming more drought stressed," he says. "But we wanted to use this stable isotope technique to demonstrate this for the entire 150 to 200-year period and not have any ambiguities about whether certain other studies may apply from different regions."

## Not All Carbon Is Equal

Meinzer suggested using a carbon isotope analysis because it reveals how trees historically processed carbon. During photosynthesis, trees take in water and atmospheric carbon dioxide ($CO_2$). With sunlight serving as the energy source, chemical processes convert the molecules into sugars that are the building blocks of the cellulose that forms the wood, branches, leaves, and roots of a tree, while oxygen is released to the atmosphere.

That equation doesn't reflect that not all the carbon atoms forming $CO_2$ molecules are the same. Atmospheric carbon atoms are either $^{12}C$ (with six protons and six neutrons) or $^{13}C$ (with six protons and seven neutrons). Because of its additional neutron, $^{13}C$ is heavier and travels slower through the air, thus is less available for chemical reactions. This means relatively more $^{12}C$ is taken into a tree through its stomata; these small openings on the surface of the leaves or needles control the intake of carbon dioxide or the loss of water vaper.

When $^{13}C$ does enter the tree, it's not the preferred carbon used to manufacture sugars in the leaves. However, when a tree is forced to close its stomata during hot, dry conditions to reduce water loss, the pool of internally available carbon dioxide is reduced, and the tree will then be forced to incorporate more $^{13}C$ into these sugars. Additionally, photosynthesis decreases, and when this happens over subsequent months, such as during the summer, the tree's overall growth decreases.

"If you go through a series of tree rings, extract the cellulose of the tree ring, and look at the carbon isotope ratio, the higher amount of $^{13}C$ to $^{12}C$ should indicate more closed stomatal pores in the leaves, which would be assumed to be an indicator of drought," explains Meinzer.

From Merschel's collection of 2,907 tree cores, Merschel and Voelker chose eight ponderosa pine and five grand fir trees for the carbon isotope analysis.

"We picked sites that had a variation in historical tree composition," Merschel says. "We wanted the cores from plots that were ponderosa pine dominated historically, to plots that had grand fir historically, so dry to wet."

It might seem counterintuitive that trees growing on relatively wet sites can experience drought stress, yet because of wildfire suppression, this can happen. "When we remove fire in the moist areas, they're the areas that really take off in terms of adding basal area and extra trees," explains Merschel. "In the Pacific Northwest, May through October is typically pretty dry, so those wet sites experience the same drought stress as the drier sites, especially if they have more trees."

Basal area is a measurement that quantifies the area of trees within a given unit. The basal area of an individual tree is calculated by measuring the tree's diameter of at breast height (dbh), which is 4.5 feet above the ground, and plugging it into this equation: basal area = $0.005454154 \times dbh^2$.

Voelker and a lab assistant performed the painstaking work of cutting up each of the tree core's rings to extract the cellulose. "It can be quite tedious at times," he admits. "It's hard to do that more than 4 to 5 hours in a day. It becomes hard on your eyes and your neck from craning over that much."

The cellulose from each ring was ground up and sealed in a filter bag. These thousands of bags were then exposed to a bleaching solution to remove the lignin, resin, and hemicellulose from the cellulose, from which the $^{13}C$ to $^{12}C$ ratio could then be determined.

## *Time Traveling Through Tree Rings*

Because drought stress was central to the study, the team looked at several weather variables that are indicators of dryness in relation to the $^{13}C$ to $^{12}C$ ratio. One variable was the Palmer Drought Severity Index, which is an estimate of dryness based upon precipitation and temperature. "What we observed is that the strength of the relationship between the tree-ring carbon isotope ratios and the Palmer Drought Severity Index increased substantially throughout the 20$^{th}$ century and into the first part of the 21$^{st}$ century," explains Voelker. "The main takeaway is that the observed increase in drought sensitivity corresponded closely to an increasing fire return interval following fire suppression in those forests."

The team also looked at vapor pressure deficits during summer months and the $^{13}C$ to $^{12}C$ ratio; the higher the vapor deficit, the stronger trend of reduced discrimination against $^{13}C$. "Stomata in leaves usually respond, in most species, to increasing vapor pressure deficit," Meinzer says. "It's an indication of the atmospheric evaporative demand." Again, there was an indication of increasing drought stress for both ponderosa pine and grand fir.

To further confirm their findings, the team delved deeper into the leaf and analyzed the relationship between internal leaf concentrations of $CO_2$ and the rate of photosynthesis. This work drew upon the photosynthesis curves of old-growth ponderosa pine modeling that Danielle Ulrich, an assistant professor at the University of Montana, did for her graduate research with Meinzer. These curves represent the relationship between stomatal conductance and photosynthesis. By comparing the historical photosynthesis curves to those after wildfire suppression began, the rate of photosynthesis decreased by 10 percent since 1830, compared to increases expected as a result of increasing levels of atmospheric $CO_2$. The likely cause of photosynthesis undershooting that which was expected was drought-stress-induced stomatal closure resulting from increasing competition following fire suppression.

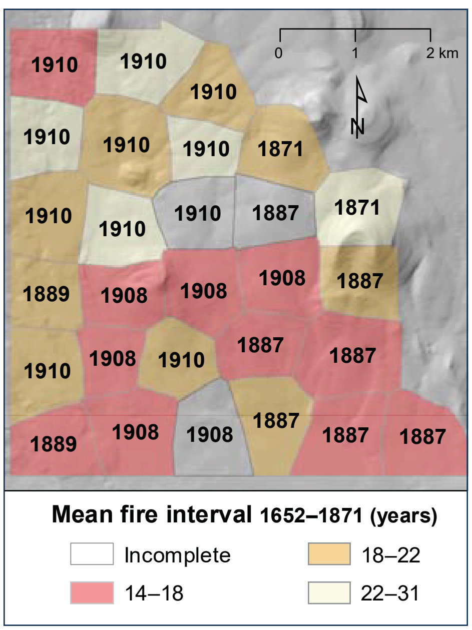
One finding that caught the team's attention was that not all the sampled trees exhibited the same levels of drought stress, which was an indication that some trees have a greater drought resistance than others. To determine a reason for this, they reconstructed an estimated basal area around 1910 to see if there was a relationship between basal area and present-day drought stress.

They found that a historical basal area less than 100 square feet per acre positioned the trees to be better able to withstand present-day drought stress than those stands in which the historical basal area was greater than 100 square feet per acre.

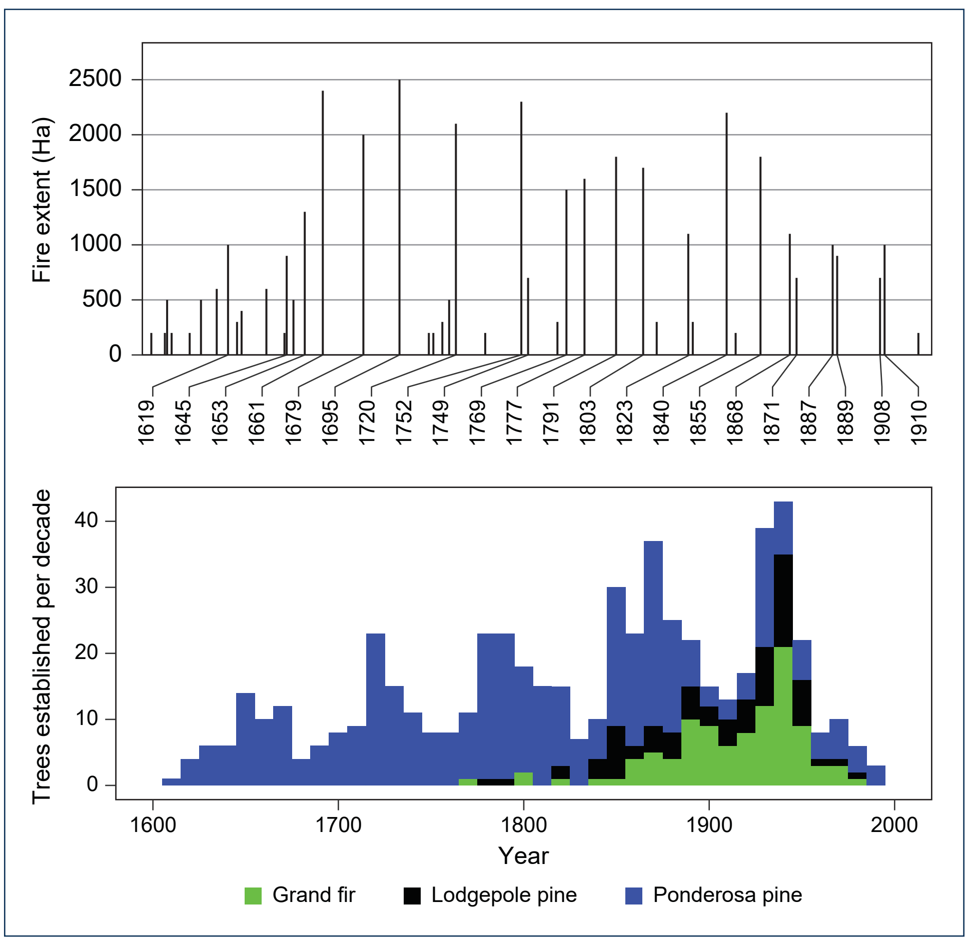
"What this confirms is that forest management can have drastic impacts on a tree's physiological responses to subsequent drought," says Ulrich.

## *Managing for a Drier Future*

While the immediate use of the study's findings is that managers now have a basal area threshold to guide future management activities and more support for returning wildfire to




*From the fire scars and tree cores collected from the study area in central Oregon, researchers reconstructed the timing of the wildfires and when trees appeared on the landscape. After 1910, the number of trees on the landscape increased noticeably. Adapted from Voelker et al. 2019.*



the landscape, the findings also provide ecological considerations when managing these dry mixed-conifer forests.

"When we talk about forest restoration, we often talk about resilience, creating resilient forests," Merschel explains. "Resilience implies that something happens to a forest and it's able to recover to what it was before. Resistance implies that when a disturbance or a drought comes along, the system maintains its structure and function. Our study says that historically forests were always understocked because of wildfire and that made them drought resistant."

As a landscape ecologist, Spies already had insight as to the relationship between the plants and their environment. Now, with the use of carbon isotope analysis, "suddenly we can tell what is going on in the life of a tree," he says. "It gives us a deeper understanding of the need for restoration and how trees are sensitive to their environment, their neighbors."

Another takeaway from this study that all the team members cited was the value of combining expertise from multiple disciplines to answer a research question.

"Without all these pieces of evidence [the detailed fire history, the tree cores, the carbon isotope analysis, and the photosynthesis modeling], the story couldn't really come together, and we couldn't come to the conclusions we did," Ulrich explains. "What makes this study even more important is that we are combining different tools, different scales, to further support more interdisciplinary research."

*"The scientific mind does not so much provide the right answers as ask the right questions."*

—Claude Levi-Strauss, Anthropologist

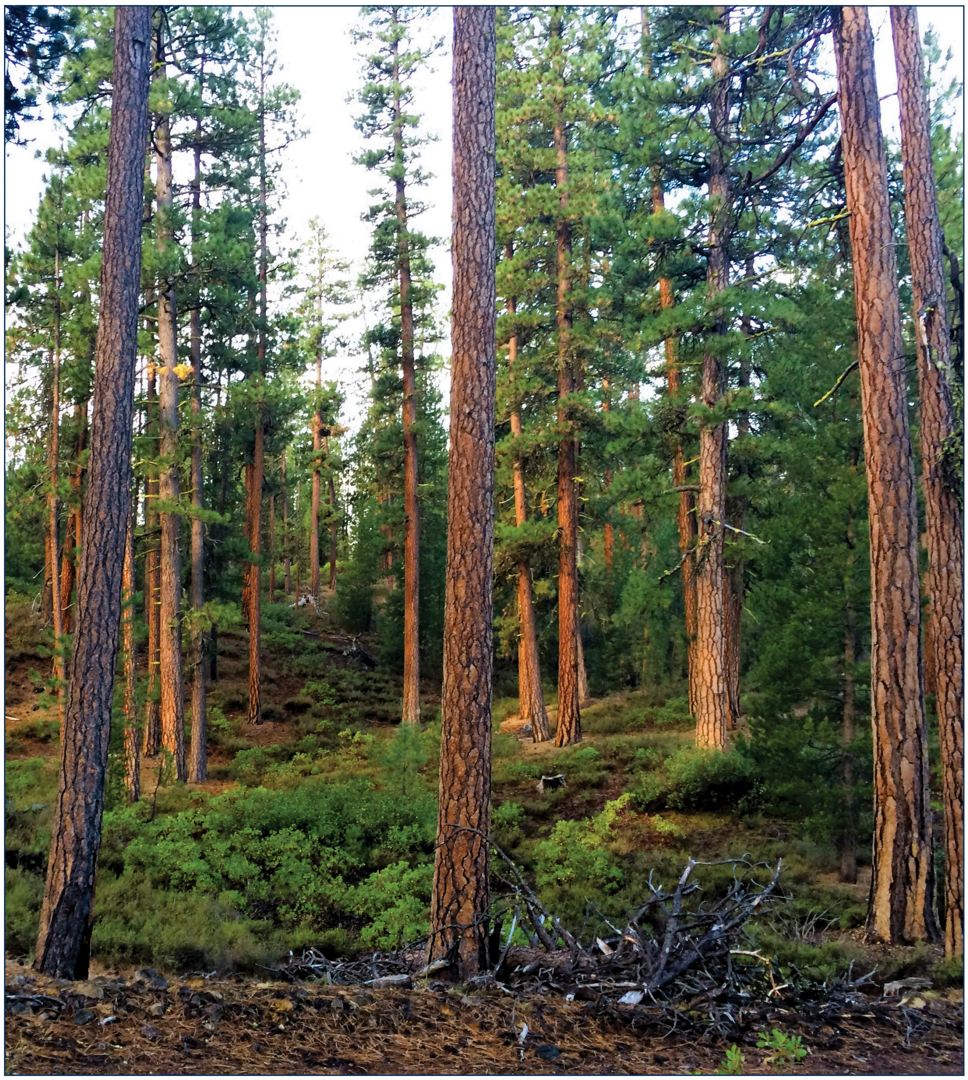
## For Further Reading

Voelker, S.L; Merschel, A.G.; Meinzer, F.C. [et al.]. 2019. Fire deficits have increased drought sensitivity in dry conifer forests: fire frequency and tree-ring carbon isotope evidence from central Oregon. Global Change Biology. 25(4): 1247–1262. https://www.fs.usda.gov/treesearch/pubs/59101.

Voelker, S.L.; Brooks, J.R.; Meinzer, F.C. [et al.]. 2016. A dynamic leaf gas exchange strategy is conserved in woody plants under changing ambient $CO_2$: evidence from carbon isotope discrimination in paleo and $CO_2$ enrichment studies. Global Change Biology. 22(2): 889–902. https://www.fs.usda.gov/treesearch/pubs/53171.

## LAND MANAGEMENT IMPLICATIONS

- Judicious use of wildfire may be key to managing for drought resistance in mixed-conifer forests that historically had a frequent-fire regime at the landscape scale.
- Mechanical thinning and use of prescribed fire to lower stand densities appear necessary to prevent mixed-conifer forests from crossing a threshold that makes them less resilient to insects and pathogens that can kill or severely reduce productivity of trees and high-severity wildfire.
- Trends of increasing heat and drought severity along with decreasing snowpack are likely to intensify the impacts of fire suppression on drought sensitivity observed in this study.



Andrew Merschel

*This stand of multi-aged, old-growth ponderosa pine in the Deschutes National Forest illustrates forest structure that is drought and fire resistant. These forest conditions were common historically across most of the range of ponderosa pine in Oregon, but are rare today.*

## Writer's Profile

*Andrea Watts is a freelance science writer who specializes in covering natural resources topics. Her portfolio is available at www.wattsinthewoods.com. She can be reached at andwatts@live.com.*

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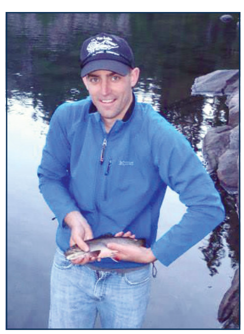

ANDREW MERSCHEL is a Ph.D. student at Oregon State University. His current research is reconstructing spatial variation in historical fire regimes and forest dynamics of forests on the central Oregon Pumice Plateau and on the western slopes of the Oregon Cascade Range.

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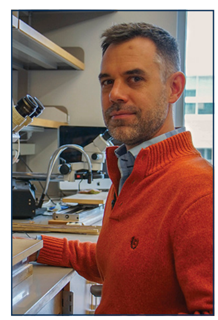

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