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Science FINDINGS

INSIDE

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

Extreme Weather, Forest Structure, and Burn Severity: Insights from the Pacific Northwest's 2020 Labor Day Megafires

A severely burned area 1 year after the 2020 Labor Day fires in western Oregon. It is one of many areas that burned at stand-replacing intensity by fires driven by a rare, extreme wind event and extremely low fuel moisture. Forest Service photo.

"An ill wind that bloweth no man to good."

–John Heywood, English writer

In Oregon on September 7, 2020, the Holiday Farm Fire ignited on the east side of the Cascade Range, followed by the Eco Mountain Fire ignition. And the Two Four Two and Clackamas County Fires, as well as the Slater and Devil Fires. The Beachie Creek Fire and Lionshead Fire, both started August 16 by lightning, were small until gusty winds propelled their explosive growth. On September 8, the Riverside Fire started. The Archie Creek and South Obenchain Fires also took hold. And the Brattain and Almeda and Thielsen Fires. And in southwest Washington, the Big Hollow Fire ignited.

Because of a rare weather pattern that generated downslope wind gusts close to 100 miles per hour, many of the smaller fires merged to collectively form six megafires: Big Hollow, Riverside, Lionshead, Beachie Creek, Holiday Farm, and Archie. These fires burned more than 1 million acres across state, private, and federal forest land. Some forests were lightly burned by surface fire, whereas others were reduced to vast, severely burned patches spanning thousands of acres on which all or most vegetation died.

IN SUMMARY

In 2020, six wildfires burned more than 1 million acres over the Labor Day weekend in Oregon. Jeremy Fried, a research forester with the U.S. Forest Service, Pacific Northwest Research Station, saw an opportunity to study how these wind-driven megafires affected forest structure and carbon storage, and how forest structure before the fires may have influenced fire severity.

With research fellows Sebastian Busby and Angela Klock, Fried developed a model that estimated wind speed when wildfire entered forest plots previously inventoried through the national Forest Inventory and Analysis program. They found that under the hot and very dry weather conditions of the Labor Day fires, forest structure influenced fire severity only when wind speeds were low (less than 5 miles per hour, for example). Tree survival in young stands was much lower than in mature forest when fire arrived with low wind speed. When winds were high, all stand age classes experienced high mortality.

The researchers also used postfire observations of soil and tree burn severity to validate the accuracy of two commonly used burn-severity map products derived from satellite data. The burn-severity maps were somewhat consistent with on-the-ground observations, but remote sensing can only detect fire effects on the overstory canopy, which aren't always closely related to fire effects on soils and understory vegetation and trees.

Sebastian Busby, then a research fellow with the Oak Ridge Institute for Science and Education (ORISE) and hosted by the U.S. Forest Service, Pacific Northwest Research Station at the time, accompanied Jeremy Fried, a research forester with the station, on a site visit to a burned stand. "It was very stark," Busby recalls. "You have all these standing dead trees for miles and miles in front of you."

The researchers also noticed that the top 1–2 feet of soil were gone. They hypothesized that this resulted from the combined combustion of soil organic matter and upward transport of mineral soil into the smoke plume. "Not only is there all this tree mortality, but the rich stores of carbon and organic material that these temperate rainforests are known for are drastically reduced," Busby says.

Fried has spent a significant portion of his career chasing fires, specifically those that burn through plots where the Forest Service's Forest Inventory and Analysis (FIA) program has collected monitoring data at 10-year intervals. Beginning with the 2002 Biscuit Fire that burned nearly half a million acres in southwest Oregon, Fried has studied how stand conditions before a fire may have influenced conditions after the fire. Land managers can then use this information to determine what forest management techniques can limit the severity of future fires.

Facing a set of very large fires to chase, in a wetter region of the Oregon and Washington Cascades where large fires have been exceptionally rare over the past half-century, Fried acted swiftly to align resources and partners.

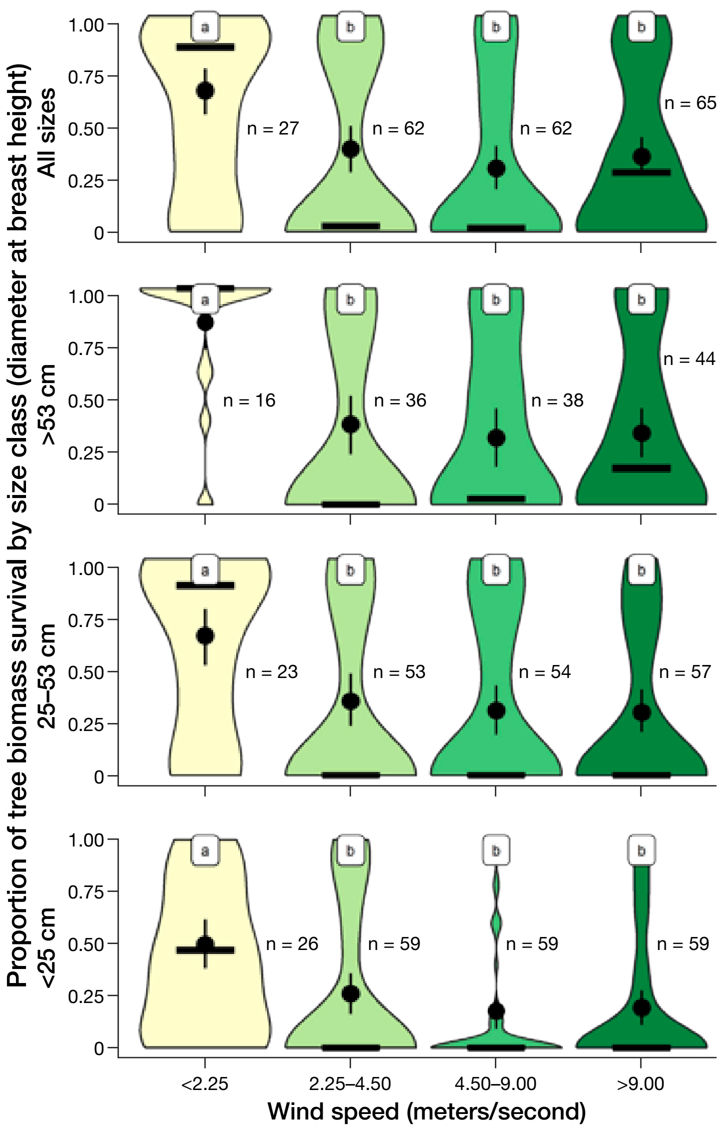
"It was a serendipitous event where we had funding available through our landscape resiliency program and a unique opportunity to rapidly remeasure these plots after the fires," recalls Andrew Yost, a forest ecologist with the Oregon Department of Forestry. Since 2007, Yost has worked with FIA data to better understand the carbon dynamics of Oregon forests.

"Because large fires in the Cascades are rare, at least in recent history, we don't have a good measure looking back," adds Danny Norlander, a forest climate carbon and health analyst with Oregon Department of Forestry. "This provides a first real opportunity for us to look at what happens following an extreme, wind-driven fire."

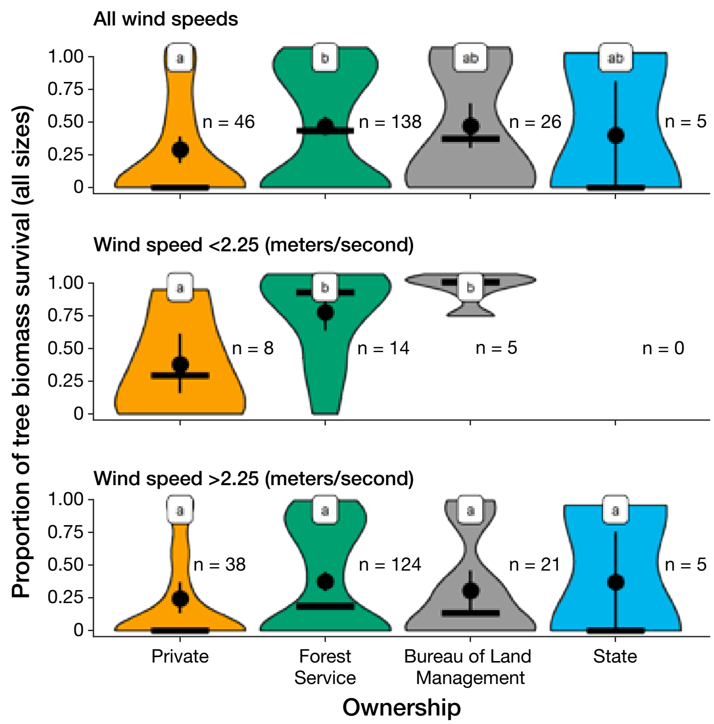
The Labor Day fires burned a comparatively small area of state-managed forestland relative to other landowners. However, the Oregon Department of Forestry supported this study, anticipating that its findings would inform the technical assistance regarding fire preparedness and postfire recovery that it provides to industrial and family forest land owners.

The influence of fire weather on tree survival

To learn if forest structure could mitigate the effects of extreme fire weather, Fried coordinated with Oregon Department of Forestry; the U.S. Department of the Interior, Bureau of Land Management; and the Forest Service's Pacific Northwest Region field crews to collect data from 261 FIA plots



◀ *Distribution of the proportion of live-tree biomass that survived 1 year after the fires by tree size and modeled, plot-local, wind speed-class when fire arrived. At lower wind speeds, smaller trees experienced low survival rates compared to large trees. Under high wind speeds, even mature and older trees had low survival. In this figure, the width of the colored shape indicates the number of plots at a given level of survival. Adapted from Busby et al. (2023).*



▲ *Distribution of the proportion of surviving tree biomass by forest owner group and modeled wind speed at fire arrival. Under light winds, tree survival was lower in privately owned forests relative to Forest Service lands. Under moderate to strong winds, mature and older forests more typically found in federal and state forests also experienced low survival. Adapted from Busby et al. (2023).*

within the fire perimeters west of the Cascade crest in the 2 years following the Labor Day fires. These plots represented 750,000 forested acres. With this postfire field data, Fried, Busby, and Angel Klock, another ORISE research fellow hosted by the station, could then compare it with prefire data from the same plots to generate a comprehensive accounting of fire outcomes with respect to tree survival and crown damage, carbon storage, and soil burn severity.

Estimating the weather when fire arrived at each plot was crucial because it is nearly impossible to assess effects of structure on fire outcomes without accounting for the influence of weather. While temperatures remained hot and forest fuels were severely dry throughout most of the fires' growth, wind speeds fluctuated significantly, dropping from nearly 100 to 0 miles per hour within a few days.

"Burn severity was so heterogeneous across the landscape. Most plots were either severely burned or very lightly burned, with not so much moderate-severity burning in the middle," says Klock. "The way that high winds drove these fires made it clear that to find any signal in the effect of forest structure would require accounting for wind when fire arrived."

Daily fire perimeter data came from U.S. National Infrared Operations, and the Weather Research and Forecasting model developed at the University of Washington generated estimates of hourly weather data, such as wind speed and direction, temperature, and relative humidity.

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KEY FINDINGS

- The 2020 Labor Day fires in Oregon and southwest Washington killed nearly all trees on 300,000 acres of forest land in the study area. Mortality rates in privately owned forests, where trees are typically younger and smaller, were greater than on federal lands regardless of the wind speed when fire arrived.
- Forest structure strongly influenced the extent to which tree crowns burned, and the likelihood of trees surviving, when winds were low. Forest structure was far less influential under high winds.
- The fires released 70 million metric tons of carbon stored in the live-tree carbon pool—more than all human-related greenhouse gas emissions generated within Oregon in 2020. Combustion of leaf and twig litter and duff on the forest floor generated immediate emissions of more than 10 million metric tons of carbon directly to the atmosphere.
- A year after the fires, many of the fire-killed trees on private land were logged and many of those logs were converted into wood products that retain stored carbon throughout the life of the product. Very few fire-killed trees were harvested from federal lands, leaving a large store of decaying wood that will release most of its carbon over the next 10 to 100 years, or serve as ready fuel for the next wildfire.
- Predictions from remotely sensed burn-severity mapping about the severity of fire damage to trees and soils were weakly to moderately related to postfire field observations. Frequent classifications of burn severity that appear inconsistent with observed fire effects warrant caution or reconsideration of the use and interpretation of these maps.

Linking the timestamps between the two datasets yielded what Fried describes as "a reasonably accurate, plus or minus a few hours, estimate of when the fire arrived at each plot, and ultimately, when linked to the weather research forecast model, the most likely weather when fire arrived." Comparing weather at fire arrival to tree survival enabled the team to understand how weather modulated the effects of forest structure on tree survival.

They found that wind speed when the fire arrived at each plot significantly affected tree survival and tree-crown damage. Under light winds, stands younger than 60 years with smaller diameter trees and often higher tree density, which predominate on private land, had the highest mortality rates. By contrast, mature stands (60–120 years) and the oldest forests (older than 120 years) with larger diameter trees and often lower tree density, common across federal lands in the study area, were relatively resistant to fire effects and experienced much lower rates of tree mortality.

These results are consistent with similar studies conducted across Oregon, the Western United States, and globally: fire is more likely to be stand-replacing in young forests, and especially industrial plantation forests, because of the typically high density of trees, thin bark found on smaller trees, and low branches that offer a ladder for fire to climb from the ground into the overstory.

The team's most striking finding was that under extreme fire weather—very dry forest fuels and high winds—even the most fire-resistant forest structures didn't forestall stand-replacing outcomes. Regardless of ownership and forest structure, of the 750,000 acres of forest land that burned in the study area, few to no live trees remained on nearly 300,000 acres.

"This research definitely influences our assumptions about where treatments that modify forest structure are going to be effective if we're shifting to a high-wind, more intense fire regime than we've seen in the past," says Dan Hubner, a geospatial analyst with the Oregon Department of Forestry.

Carbon release or salvage logging

When trees, dead wood, and the forest floor burn under extreme wildfire conditions, the stored carbon is released to the atmosphere within hours. If a fire-killed tree remains standing as a snag, and most do, it slowly decomposes until it falls and then decomposes more quickly after coming in contact with soil; nearly all of its stored carbon is released to the atmosphere in the subsequent 50 to 100 years. When a fire-killed tree is harvested and manufactured into wood products, the carbon remains trapped in the wood for the life span of the product, and possibly beyond, depending on the ultimate disposal method of the wood product.

To determine how the fire and subsequent decisions about harvesting fire-killed trees influence transfers among carbon pools, the team accounted for the differences in those pools between prefire and postfire measurements. They calculated that 70 million

A salvage logging site on private land in western Oregon after the 2020 fires. Forest Service photo.

metric tons of carbon dioxide equivalent (CO_2e) exited the live-tree carbon pool following the fires, with some emitted to the atmosphere immediately and the rest released gradually as fire-killed wood decomposed. At least another 10 million metric tons immediately entered the atmosphere as the forest floor burned. The 70 million metric tons that exited the live-tree carbon pool “was more than all the anthropogenic emissions of carbon in Oregon in the year that these fires burned, including residential and commercial heating and cooling, industrial and agricultural processes, and all forms of transportation of people and goods,” says Fried.

The release of this much carbon surprised Yost: “It has given us insight into the consequences and tradeoffs of different management choices when our forests are tested by fire burning under extreme weather, and how and when stand structure affects what gets killed,” he says.

Because postfire harvesting occurred almost exclusively on private land, a significant portion of the fire-killed carbon on those ownerships was transferred into wood products. On federal lands, salvage logging focused on removing hazardous trees along roadways. The remaining fire-killed trees are now carbon emitters.

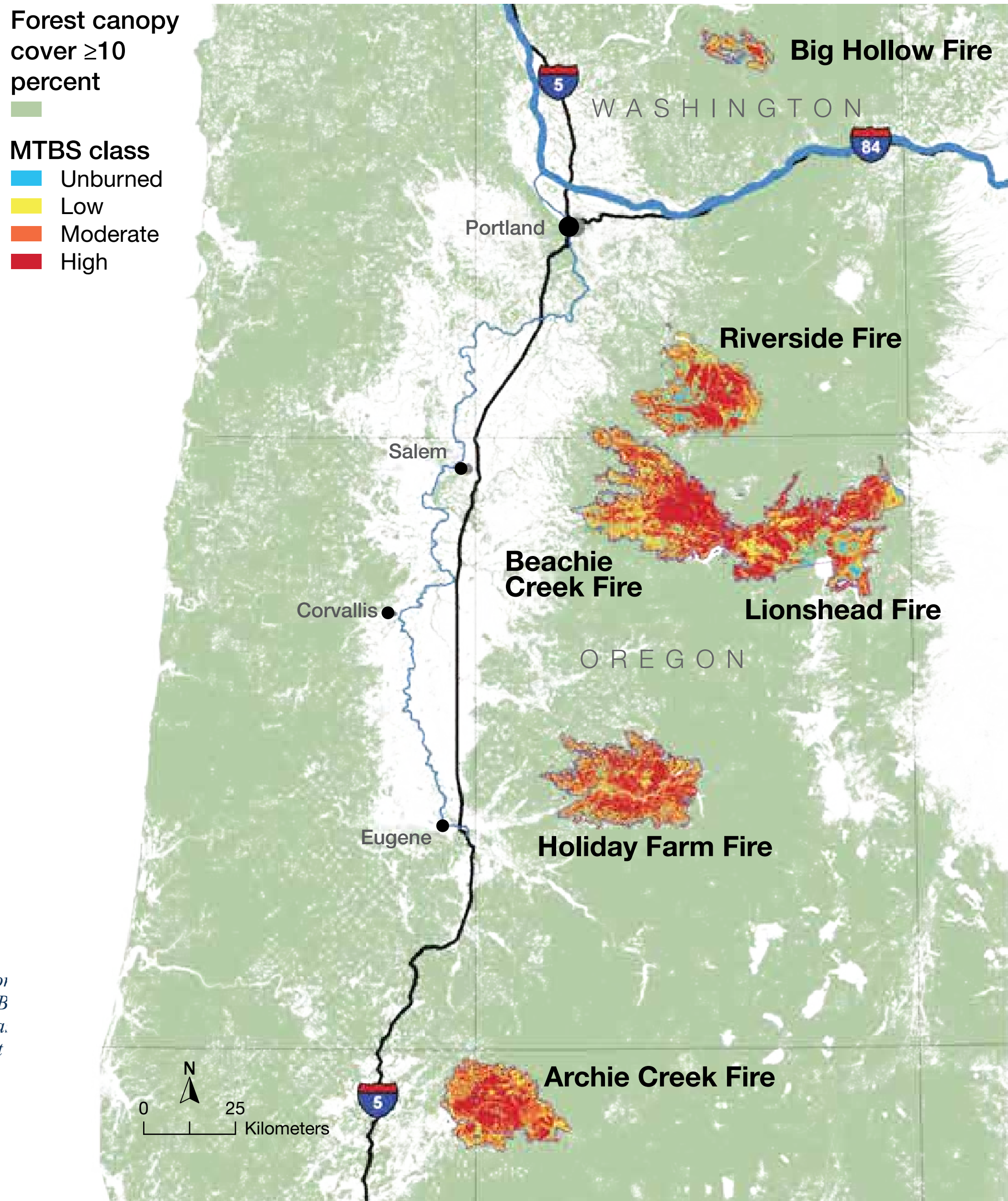
“Historically, this extreme wind-driven flavor of fire returns at very long intervals on the west side [of the Cascades]; whether such fires will recur at shorter intervals going forward is anybody’s guess,” Fried says. “The only certainty is that we will see this fire flavor again in west-side forests, perhaps within the next decade or two, and when we do, it will again be unstoppable. This highlights the importance of reevaluating just how stable these forests really are in terms of carbon sequestration and storage.”

Evaluating burn-severity maps

After a high-severity fire, there are significant implications to losing the organic soil layer, says Wendy Peterman, now retired, who served as soils program manager with the Willamette National Forest. “It’s really what holds the carbon in the system and feeds the microbes and determines a lot about the water-holding capacity of the soil,” she explains.

After a fire, land managers across the Western United States use burn-severity maps to decide where to mitigate against soil erosion, salvage log, and replant. Two such products are Burned Area Emergency Response-Soil Burn Severity (BAER-SBS) maps, to understand fire effects on soils, and Monitoring Trends in Burn Severity—Thematic Class (MTBS-TC) maps, to assess impacts to vegetation. Despite broad usage, the accuracy of these maps has been questioned by studies elsewhere in the country. After the 2020 Labor Day fires, Fried and Peterman heard anecdotally that the resulting postfire BAER-SBS maps didn’t align well with on-the-ground observations.

When the FIA crews remeasured plots that had burned, they observed that, in some cases, not only was most of the organic soil cover missing but mineral soil was missing, too. In some places, 1 to 2 feet of soil had disappeared. This was detectable because FIA crews place and maintain nails in all trees on these permanent plots to indicate where to measure tree diameter. The nails are 4.5 feet above ground to ensure future remeasurements are taken from the same location. After the fire, crews found that some of these nails were much higher. This could only be explained by a change in ground level because the nails are embedded in the tree and hadn’t been moved.



Burn severity map for the 2020 Labor Day fires based o sensed Monitoring Trends in Burn Severity (MTB significant portion of the burned area was classified a. moderate-severity burns. Adapted from Busby et

"We nicknamed this phenomenon soil drop because it was as though the soil had dropped four inches," Peterman explains.

Now, Fried and his team could test the accuracy of the maps generated by the BAER-SBS and MTBS-TC models by using the postfire FIA plot data.

They found that BAER-SBS maps overstated soil burn severity across 40 percent of the plots in the unburned low category, relative to the organic matter cover observed there. Conversely, the model understated burn severity across 15 percent of the plots where field crews observed no organic cover.

In terms of MTBS-TC's characterization of fire effects on trees, the team determined that this map was most accurate at classifying high-severity fire where few or no live trees remain, yet it exhibited poor to moderate accuracy in classifying other levels of severity. Notably, it categorized some plots as unburned or burning at low severity but field crews determined that those plots experienced considerable tree mortality.

Because these burn-severity maps are easy to use and frequently updated, they are widely used by managers and scientists who may not be aware of the maps' limitations, says Busby. "While our research suggests these maps have some shortcomings, increasing awareness around those shortcomings can ideally prevent their misuse and drive new research to improve them."

LAND MANAGEMENT IMPLICATIONS

- Forest management that promotes fire-resistant forest structures could reduce stand-replacing fire in forests on the west side of the Cascade Range, except under the most extreme conditions, such as high winds combined with very dry forest fuels.
- When burned during extreme fire weather, old, carbon-rich forests on federal lands transfer much more carbon into dead-wood pools than young, private forests. Timely salvage following stand-replacing fire could reduce future carbon emissions from the decaying dead wood, as could repeated partial harvests that would reduce canopy fire initiation and tree mortality during future fires, except under the most extreme weather.
- Commonly used burn-severity maps generated from satellite data can poorly represent actual field conditions, potentially reducing the effectiveness of postfire management that is based on these maps.

Hubner points out, "When we get called upon in areas where we don't necessarily have a regulatory role but as the state's expert forestry agency to give forestry input on these topics, it's really useful to know the limitations of all these map products derived from remote-sensing data."

Collaboration

What sets the 2020 Labor Day fires apart from other historic wind-driven megafires, is the collection of postfire data linked to prefire measurements and ongoing monitoring of the postfire trajectories. Researchers are using these measurements to more fully understand the implications of these fires for carbon storage, wildlife habitat, and timber production. In the past, research on wind-driven megafires was largely retrospective, sometimes centuries after a fire. That approach required deductions based on contemporary forest structure and analysis of tree core samples and fire scars as well as anecdotes. That state and federal agencies pooled funds to support this recent research demonstrates the recognition that investing in science can generate long-term dividends.

"We're definitely interested in the regeneration that comes after these fires, so that's where the value of this research will keep on delivering into the future for us, for a few dollars relatively speaking," Yost explains. "This analysis and rapid assessment of the plots is going to keep on delivering into the future."

"Most achievements in science are to a certain degree group efforts."

—Willard F. Libby, American scientist

For Further Reading

Busby, Sebastian U.; Klock, Angela M.; Fried, Jeremy S. 2023. Inventory analysis of fire effects wrought by wind-driven megafires in relation to weather and pre-fire forest structure in the western Cascades. Fire Ecology. 19(1): 58. https://doi.org/10.1186/s42408-023-00219-x.

Klock, Angela M.; Busby, Sebastian; Fried, Jeremy S. 2023. It's about time: a method for estimating wildfire arrival and weather conditions at field-sampled locations. Fire. 6(9): 360. https://doi.org/10.3390/fire6090360.

Writer's Profile

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Fire burned with high severity at this site in Oregon, releasing considerable stores of carbon from soil organic matter to the atmosphere. Forest Service photo.

Forest regeneration 1 year after the 2020 Labor Day fires. Forest Service photo.

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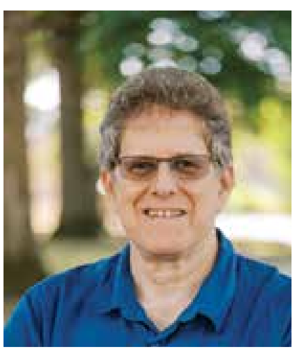

JEREMY FRIED is a research forester with the Pacific Northwest Research Station. He conducts research leveraging forest monitoring data and forest growth, operations research, and geospatial models to understand how forest and fuels management can feasibly and effectively promote fire resistance while also delivering timber, utilizable woody biomass residues, habitat, and other ecosystem services like the climate benefits that carbon sequestration can provide.

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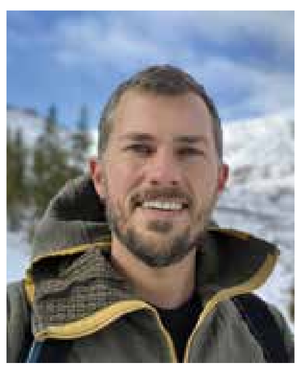

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