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Science FINDINGS

INSIDE

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

Timing Is Everything!
Insights From Douglas-fir Response to the 2021 Heat Dome

A Forest Service scientist downloads data from a weather station at a research site on Roseburg Forest Products property in Oregon. USDA Forest Service photo.

IN SUMMARY

Douglas-fir is the primary timber species in the Pacific Northwest. Successful reforestation after wildfire or harvest requires planting Douglas-fir seedlings that will thrive in that location. Different populations of the same species have slightly different growth habits. Selecting the right seed source for a site is critical to success.

The Pacific Northwest's unprecedented heat dome in 2021 created June temperatures that were 35 to 45 °F higher than average. Connie Harrington and Rich Cronn, scientists with the U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, used this heat event to determine if extreme heat causes Douglas-fir to stop growing earlier in the season than under "normal" temperatures and if different seed sources responded differently to the extreme heat.

They found that diameter growth stopped early in 2021 compared to other years. In 2022, for example, summer temperatures stayed within the historical average and trees grew 125 to 370 percent more than in 2021.

Across all sites, location and seed source determined when trees experienced early growth or cessation. Trees on lower elevation sites grew earlier in the year and later in the fall. Seed sources from sites with continental climates (cold winters, hot summers, and little rainfall) had substantial early season growth. These findings are helping to ensure the productivity of public and private forests in the region.

"The world is but a school of inquiry."

–Michel de Montaigne, French philosopher

On June 27, 2021, the overhead signs on I-5 flashed a message to travelers: "What are you doing on the highway?" With air temperatures reaching or exceeding 110 °F along the I-5 corridor from Ashland, Oregon, to Seattle, Washington, (a region where average June temperatures range from the 60s to the low 80s), public officials encouraged people to stay inside. Rich Cronn, a research geneticist with the U.S. Department of Agriculture, Forest Service, Pacific Northwest (PNW) Research Station, was one of those drivers on the highway, driving to Tacoma to visit a bigleaf maple trial site. A couple of days later, on the drive home, Cronn stopped at some sites in the Portland area to examine Douglas-fir and western redcedar trees whose green needles were now red, scorched by the intense heat.

"I remember thinking, 'This is significant. There is going to be substantial damage on the trees,'" he says. Farther south at a Forest Service study site in Monmouth, Oregon, trees didn't show severe foliage damage, which led Cronn to conclude that the scorching may not have been entirely due to the high air temperatures, but instead a combination of high temperatures, tree species, and site conditions.

This 2021 heat event, which stretched from northern California to southern British Columbia, was dubbed the “heat dome.” A few days after the heat subsided, Cronn and several station researchers held an emergency discussion. Connie Harrington, an emeritus research scientist whose Forest Service research career spans 42 years, was on the call.

The heat dome event provided an opportunity to determine if high temperature alone could cause Douglas-fir to stop growing, as proposed by the “summer cessation” hypothesis and model developed in 2015 by Kevin Ford, the assistant director for Forest and Range Management with the Forest Service’s Pacific Northwest Region; Harrington; and Brad St. Clair, a retired research geneticist with the PNW Research Station.

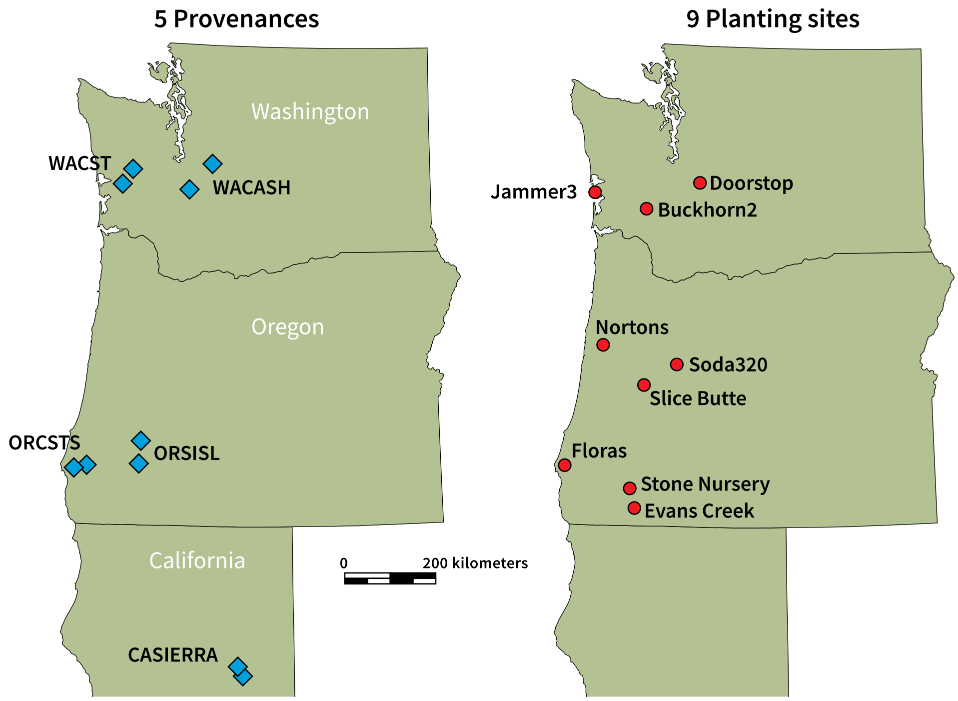
“Ford, Harrington, and St. Clair made a prediction from the Douglas-fir Seed-Source Movement Trial that was novel to Douglas-fir,” Cronn explains. “The prediction was that if Douglas-fir experiences a specific critical temperature greater than 107 °F during the long days of summer for several days, it will simply shut down diameter growth for the remainder of the year.”

This prediction was based on data from trees growing on a site in Oregon that experienced unusually high temperatures during the summer solstice of 2015. The heat dome of 2021 provided an opportunity to see if the predicted growth shut down, or cessation, would be observed at any sites within the Douglas-fir Seed-Source Movement Trial. But to do so, the researchers had to move quickly to measure the current diameter of the trees.

“Basically, it was Rich and I, and whoever we roped into going with us,” Harrington says. “We both felt it was really important to get immediate measurements so we could see [the diameter growth] at the end of the year. We wanted to test the model of diameter growth cessation and also see if our model of spring budburst could help understand why scorch was very prominent in some locations but minor or not observed at all in other places.”

The Douglas-fir Seed-Source Movement Trial

Established in 2009, the Douglas-fir Seed-Source Movement Trial (SSMT) is a long-term research project that Harrington and St. Clair spearheaded; it is currently managed by Beth Roskilly, a research geneticist with the PNW Research Station. The study is evaluating how Douglas-fir populations respond to different environmental conditions and includes building predictive models that help foresters mitigate the effects of climate change on Douglas-fir reforestation. Seeds were collected from 60 populations, or seed-source provenances, across



The Douglas-Fir Seed-Source Movement Trial consists of nine sites located in Oregon and Washington. To assess the effect of extreme heat, researchers monitored diameter growth of trees from five provenances (seed sources) planted at each of these nine sites.

A Forest Service scientist measures a tree at the J. Herbert Stone Nursery in Oregon to determine seasonal diameter growth rates. USDA Forest Service photo.

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Rhonda Mazza, editor; rhonda.mazza@usda.gov

Jason Blake, layout; jason.p.blake@usda.gov

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northern California, Oregon, and Washington, and seedlings from each seed source were planted at nine sites in western Oregon and Washington. These sites are on land managed or owned by Cascade Timber Consulting, Giustina Land and Timber, Lone Rock Timber, Manulife Investment Management, Port Blakely, Roseburg Forest Products, Starker Forests, Washington Department of Natural Resources, and the Forest Service.

Of these nine sites, Harrington and Cronn visited two sites in Oregon and two sites in Washington within 16 days after the heat dome event. On each site, they measured 36 trees representing three seed-source provenances. To fully understand how the heat dome impacted diameter growth, they wanted to measure changes in growth at different times of the 2021 growing season and then compare these patterns of diameter growth in 2022. Harrington and Cronn determined that additional measurements were needed at five different times during the next year: at the end of the 2021 growing season; and in May, late June to early July, early to mid-August, and October to early December of 2022. Additionally, they wanted to compare the data at all nine sites, but to do so, the measurements needed to be collected around the same time at each of the nine sites.

“It’s important to look from the beginning of the year and through these intermediate periods because some of the populations might start growing earlier based upon site conditions,” Harrington explains.

Such extensive data collection on a narrow timeframe wasn’t possible with the limited staff on hand, which meant they needed more help in the field.

KEY FINDINGS

- Diameter growth in Douglas-fir in 2022 from late June to the end of the growing season was 125 to 370 percent more than in 2021 during the same period due to early growth cessation in 2021 associated with extreme heat. Phenology models developed in 2015 predicted this response.
- An existing model projecting the timing of spring budburst was useful in understanding why no scorch was observed on the hottest sites in 2021; those sites had early budburst, and the mature foliage was not as susceptible to the extreme heat.
- In 2022, seed sources from sites with continental climates had substantial early season growth.
- In 2022, trees had little diameter growth after early August on high-elevation sites (2,300 feet and higher). Trees from most seed sources continued growing late in the season on coastal sites.

When Is Growing Time?

Why was it necessary to measure diameter growth throughout the year? It’s all tied to phenology. “If you say phenology, most people think about budburst,” Harrington explains. “In fact, phenology is the study of when seasonal events happen, such as when the buds open, or when diameter growth starts and stops, or even when trees flower. It encompasses the whole period of growth.”

Understanding the timing of diameter growth of Douglas-fir is important because this conifer is a valuable species in the Pacific Northwest, both for ecological and economic reasons. Douglas-fir has been studied for decades so the timing of diameter growth is well documented, as is the yearly average diameter growth.

“They start growing in diameter in early March through early May, and the growth is fairly rapid and of a short duration,” explains Harrington. “Typically, the majority of growth happens over the first two or three months.” However, most past research has focused on only a few locations and under past weather conditions that may not represent conditions in the future.

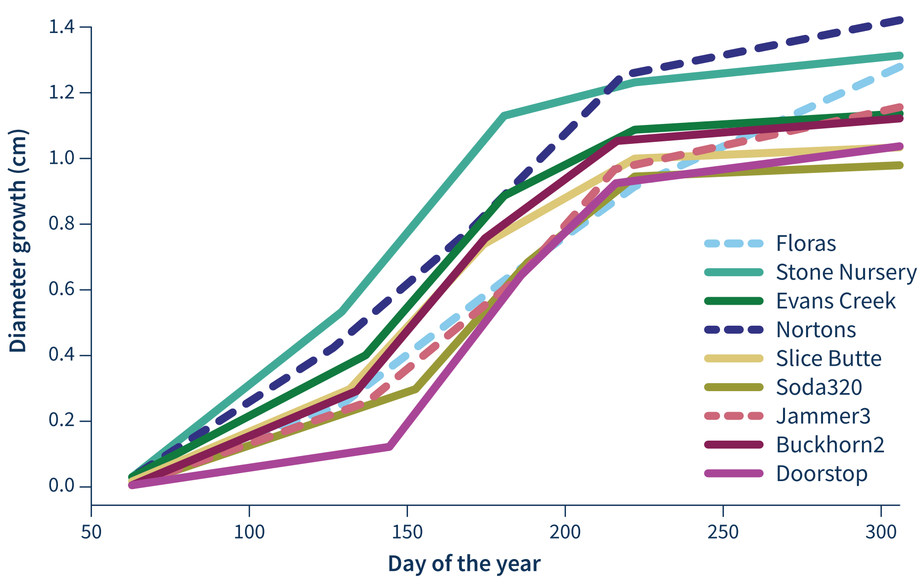
The growth and yield models used by foresters to calculate harvest volumes include tree diameter. However, these models were developed based on measurements collected decades earlier under a different—and specifically, a cooler—climate. With climate change causing unexpected heat events in late spring and early summer, like the 2021 heat dome, these temperatures may be hot enough to prompt Douglas-fir to stop growing weeks sooner than they would have under historical average temperatures. Alternatively, warming spring temperatures could prompt trees to start growing earlier in the year. As a result, current growth and yield models may significantly underestimate or overestimate growth for a given year.

By collecting diameter measurements through 2022 at all nine sites, Harrington and the team could also compare the late-season diameter growth in 2021 to 2022’s growth to see if the summer cessation could be observed across the sites and seed-source provenances.

Volunteers to the Rescue

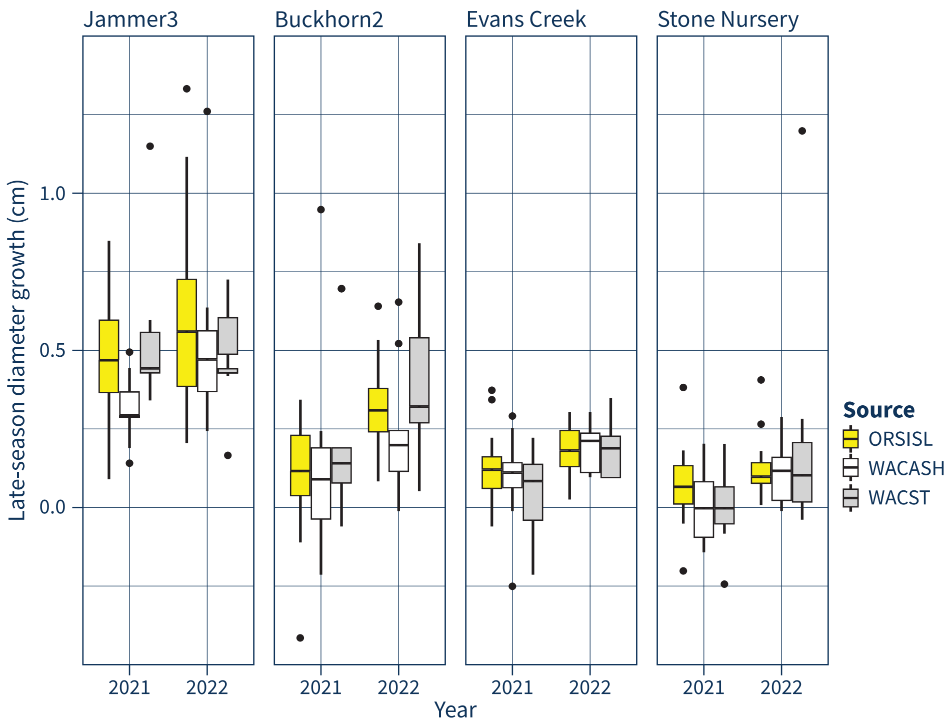
Harrington reached out to the landowners who host SSMT sites and asked for help collecting the needed measurements throughout the year. For this study, volunteers used a low-precision measurement device (diameter tape) to make repeated diameter measurements on the same day across nine sites. The repeated measures at marked locations on the tree stems reduced the error of individual measurements, and this allowed the scientists to identify subtle differences in diameter growth rates across sites and years.

Mike Backen, a district forester for Lone Rock Timber, was one of these volunteers. He



Cumulative diameter growth during the 2022 growing season at nine planting sites. Trees at the three coastal sites (dashed lines) continued growing later into the year. From Harrington et al. (2023).

higher, there was little diameter growth after early August. Their analysis also revealed that past infections of needle disease negatively affected growth and that trees sourced from the California Sierra provenance had poor growth when grown on moist, cool sites.



Differences in late-season diameter growth in 2021 and 2022 at four sites in trees from three seed sources could be attributed to the 2021 heat dome. Overall, diameter growth was greater in 2022. Sites where temperatures exceeded 107 °F for two or three days in 2021 had the largest difference between the two years. From Harrington et al. (2023).

The scorch damage observed after the 2021 heat dome was found to be linked to timing of budburst. Scorch damage was greatest in newly emerged foliage compared to foliage that hadn't fully emerged or older, fully developed foliage. USDA Forest Service photo by Connie Harrington.

visited the site hosted by Lone Rock five times to collect the diameter measurements. "This kind of research is a tool that we can use to be successful," Backen explains. "We rely on forest science to make our land management decisions every day. This kind of partnership benefits everyone, and Lone Rock is excited to be a part of this work."

Once the final measurements were collected, Harrington, Cronn, and Peter Gould, a remote sensing and inventory analyst with Mason, Bruce & Girard and a long-time collaborator in the SSMT study, began the statistical analysis. They compared the 2021 and 2022 diameter growth for each tree and built several models to determine if growing location, seed provenance, and past infection of needle disease affected the observed diameter growth.

They determined that the diameter growth in 2022 from late June onward was 125 to 370 percent higher compared to diameter growth in 2021. Site location also played a role in the observed growth. In 2022, Douglas-fir trees at coastal sites continued growing late in the season; whereas at sites located 2300 feet and

Future Research

The extreme summer temperatures of the 2021 heat dome were unimaginable when Ford, Harrington, and St. Clair developed their phenology model for diameter growth in 2015. In this way, the SSMT is a prime example of forward-looking research that anticipates the studies and data needs for future scenarios that have yet to occur on the ground and where no information exists for making management prescriptions. "Often when a finding is published, it's not used right away, but practitioners may start to use it a few years later," Harrington explains.

"It was really gratifying that initial predictions made from the Seed-Source Movement Trial with limited data held up so well to the real-world field responses after the heat dome of 2021," says Cronn.

The addition of this study to the ever-growing body of observations collected from the SSMT can aid reforestation efforts. "If we see that, following these extreme weather events, that some seed sources do better than others, that has clear implications for selecting seed sources that can withstand these extremes," explains Jeff DeBell, a forest geneticist with the Washington Department of Natural Resources.

And Backen says, "This research is fascinating. It's all good information for us to have, and we'll try to figure out how to use it in the future for sure."

In a related line of study, researchers are investigating the differences in the amount of scorch—the first visible leaf and needle damage—in western Washington and Oregon. Harrington hypothesized that the amount of damage could be related to budburst phenology. Adam Sibley, a researcher at Oregon State University, initially used remotely sensed imagery to map tree canopy scorch in western Washington and Oregon and evaluated many factors, including aspect, slope, and geographic position. He then predicted the date of spring budburst in 2021, as projected by the model that Harrington and others developed in 2017, and looked to see how it related to the amount of scorch visible in the landscape-level, remotely sensed data. The locations with predicted early budburst (new foliage had developed several weeks before the heat event and was not as susceptible to high temperatures) and late budburst (new foliage hadn't fully emerged yet) experienced less scorch. The greatest

LAND MANAGEMENT IMPLICATIONS

- Information about how different seed sources respond to extreme weather will be key when selecting seeds for reforestation in the future.
- Planting common seed sources across sites with a range of climate conditions can yield insights into how diameter growth of the different populations will respond to future climates.
- Extreme events like the 2021 heat dome in the Pacific Northwest are useful for testing models developed under less extreme conditions. When the projections are borne out, it builds confidence in the models and utility of their output when making management decisions based on how Douglas-fir may respond to future events.
- Support and collaboration among the landowners involved in the Douglas-fir Seed-Source Movement Trial made it possible to collect data rapidly and across geographically distant sites. This approach holds promise for future data collection efforts and enables researchers to consider new lines of inquiry that may be time sensitive.

levels of leaf scorch were associated with sites with intermediate dates of spring budburst (new foliage had emerged but wasn't fully developed yet).

"It's so cool that the original model, which was based on saplings we measured and observed with our own eyes, is being compared to data being collected by satellites," Harrington explains. "Such entirely different scales yet they mesh together."

As for the next modeling project, she sees value in continuing to study diameter growth and to especially understand individual contributions of temperatures, humidity, and soil moisture. In 2022, Cronn and Rob Slesak, a research forester with the station, affixed electronic diameter instruments to a subset of trees at SSMT sites to collect fine-scale measurements over the course of multiple calendar years. These instruments collect data every 15 minutes (2,190 measurements per tree per year) and can detect diameter changes as small as 1/100th of a millimeter. "We really appreciated our volunteers helping us collect the data in 2022, but they can't match the precision or the detailed data of electronic dendrometers," said Cronn.

Additionally, Chaney Hart, a graduate student at Oregon State University, is cataloging annual changes in gene expression from the cambium of Douglas-fir, which is the wood-producing part of the tree. This study will define the genes responsible for diameter growth and identify how different genes drive the timing and magnitude of diameter growth. This work includes sampling of SSMT trees and sites to develop and test models.

"We don't have the detailed phenology models for diameter growth under all the circumstances that would allow us to predict what's going to happen," Harrington explains. "Nor do we completely understand how different genotypes respond to environmental conditions. Slowly but surely, we and other researchers are looking at different aspects of the puzzle of how Douglas-fir responds to its environment."

> *"Nothing great was ever achieved without enthusiasm."*
>
> —Ralph Waldo Emerson, American essayist

Writer's Profile

Andrea Watts is a freelance science writer based in the Pacific Northwest. Her portfolio is available at https://www.wattsinthewoods.com, and she can be reached at andwatts@live.com.

By pairing data from weather stations with the diameter measurements, researchers identified relationships between temperature and initiation and cessation of seasonal Douglas-fir growth.USDA Forest Service photo.

A Forest Service researcher downloads fine-scale growth data from a Douglas-fir tree. These became available to the researchers after taking manual measurements in 2021 and 2022. The electronic dendrometer affixed to the tree collects fine-scale diameter measurements every 15 minutes over several years. Collectively, these measurements will create a more robust picture of Douglas-fir tree growth throughout the year. USDA Forest Service photo.

For Further Reading

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Pacific Northwest Research Station
USDA Forest Service
1220 SW 3rd Avenue, Suite 1400
Portland, OR 97204

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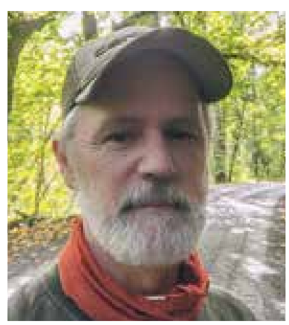
Scientist Profiles

CONNIE HARRINGTON is an emeritus research scientist with the Pacific Northwest Research Station. Her research focuses on studying plant responses to environmental conditions. She also studies silviculture techniques, such as variable-density thinning. She has a Ph.D. from the University of Washington in forest resources.

Harrington can be reached at:

USDA Forest Service
Pacific Northwest Research Station
Forestry Sciences Laboratory
3625 93rd Avenue SW
Olympia, WA 98512

Phone: (360) 753–7670
E-mail: constance.harrington@usda.gov



RICH CRONN is a research geneticist with the Pacific Northwest Research Station. His current research focus includes advancing genetic marker technologies for domestic and international timber to improve legality and to help prosecute timber theft and adopting genomics technologies for applications in forest management, such as environmental DNA. He has a Ph.D. from Iowa State University in plant genetics.

Cronn can be reached at:

USDA Forest Service
Pacific Northwest Research Station
3200 SW Jefferson Way
Corvallis, OR 97331

Phone: (541) 750–7291
E-mail: richard.cronn@usda.gov

Collaborators

Landowners who partner with the Forest Service to host the Douglas-fir Seed-Source Movement Trial include Cascade Timber Consulting, Giustina Land and Timber, Lone Rock Timber, Manulife Investment Management, Port Blakely, Roseburg Forest Products, Starker Forests, and Washington Department of Natural Resources. The Forest Service staff at the J.H. Stone Nursery are also critical in this work.

Volunteers who collected measurements for this study include Lysbeth Ackerman, Mike Backen, Cassie Berg, Leslie Brodie, William Carlson, Florian Deisenhofer, Darian Domes, Cary Hart, Andrew Hicks, Scott Kolpak, Sara Lipow, Josh Meek, Stuart Olshevski, Hunter Olson, and Fred Pfund.