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Science FINDINGS

INSIDE

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"Science affects the way we think together."

Lewis Thomas

Predicting Douglas-Fir's Response to a Warming Climate

Connie Harrington

Some populations of Douglas-fir are more drought tolerant than others. In an ongoing study, researchers are testing how seed grown from different populations respond to temperature and precipitation conditions that differ from current local conditions.

IN SUMMARY

Douglas-fir is an iconic tree in the Pacific Northwest. Although individual trees may appear to be identical, genetic differences within each tree have resulted from adaptation to the local environment. These genetic differences over time have resulted in differences among populations that are important to the species' survival and growth in changing climates.

Current climate models project that over the next 50 years, the Pacific Northwest will experience an increase in summer temperatures. Combined with less winter snowpack, warmer summer temperatures will likely lead to more frequent and intense droughts, and it is unknown how Douglas-fir will respond. Researchers with the U.S. Forest Service Pacific Northwest Research Station tested how seedlings from different populations of Douglas-fir would grow in temperature and precipitation conditions unlike the climate of their current seed source. By sampling 35 populations in three common garden sites, researchers determined how a combination of genetic factors and environmental conditions influence drought-tolerant traits.

Trees grown in a warm, dry environment had lower rates of water loss compared to seedlings grown in cooler environments. Furthermore, researchers identified populations that had high drought tolerance and relatively fast growth. This means that although Douglas-fir as a species is relatively drought tolerant, some populations are better adapted to future climate conditions than others.

"I have called this principle, by which each slight variation, if useful, is preserved, by the term of Natural Selection."

—Charles Darwin,
On the Origin of Species, 1859

Growing on millions of acres on public and private lands in the Pacific Northwest, Douglas-fir is synonymous with forestry and the scenic beauty of the region. This species is prized for its rapid growth and wood strength, which makes it ideal for milling into 2 x 4s and other products. Douglas-fir forests also sequester large amounts of carbon, are home to many bird and wildlife species, and provide stunning backdrops while hiking, to name a few of the ecosystem services they provide.

The natural range of Douglas-fir stretches from moist, temperate rainforests along the Pacific Coast to the drier forests found to the east on slopes of the Rocky Mountains. North to south, its range stretches from central British Columbia to Mexico. Douglas-fir's desirable wood characteristics have prompted foresters in Europe, New Zealand, and Chile to grow it in their respective countries to fulfill many wood product needs.

Because this extensive range spans extremes in winter temperature and summer precipitation, Douglas-fir populations have adapted to their local environmental conditions. Identifying the differences in these adaptations among populations and the mechanisms that triggered them has taken on a greater importance as land managers plan for climate change and look for trees that will grow well under projected future conditions.

"Most of the Pacific Northwest has a Mediterranean climate, which includes very dry summers," says Connie Harrington, a research forester with the U.S. Forest Service Pacific Northwest (PNW) Research Station. "The projections for climate change at the regional level are that summers are going to become hotter and drier in the future. This will result in more stressful conditions for the trees." Stressed trees grow more slowly than unstressed trees and are less likely to survive.

The Washington State Department of Natural Resources (DNR) is a major landholder of timberland in the state. Jeff DeBell, a geneticist with the DNR, welcomes research that can shed light on the genetic variability of Douglas-fir so that he and other forest managers can make informed decisions when selecting seed sources for replanting. Each year, DNR replants roughly 15,000 acres. "If we want healthy forests, we need to have a match between climate and seed source," he says.

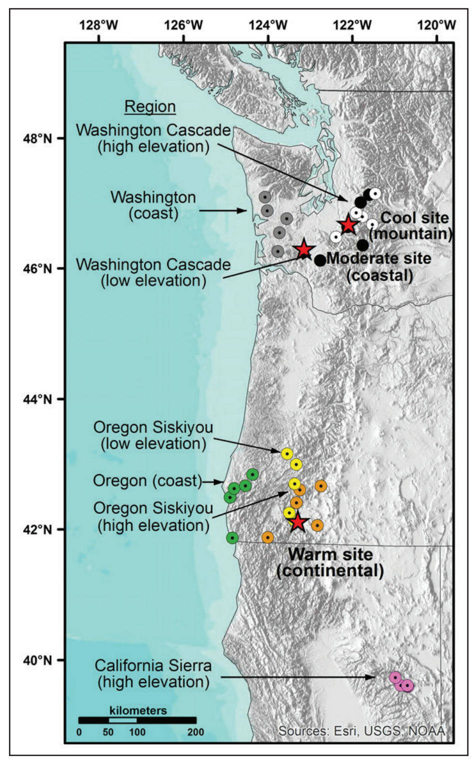
KEY FINDINGS

- Across all populations, Douglas-fir trees exposed to a warm, dry environment, which simulated predicted future climate conditions, had a 40-percent lower rate of water loss than trees grown in cooler locales.
- The populations which exhibited the highest level of drought tolerance originated in climates with cold winters and dry summers. This means that drought tolerance is a trait that can be selected for from different populations based on their seed-source climate.
- Although drought tolerance is generally associated with slower growth rates, several populations of Douglas-fir exhibited a high level of drought tolerance and relatively fast growth.

The first genetic studies on Douglas-fir began in 1912 at what is now the PNW Research Station's Wind River Experimental Forest in Washington. This early work led to the concept of Douglas-fir seed zones: seeds grow best when they are not moved too far from their source. Currently, most seedlings used in reforestation are grown from seed gathered from local Douglas-fir populations because these trees are adapted to local environmental conditions. With climate change, however, there is a concern that Douglas-fir planted in 2015 may not be well-adapted to the climate of the future. As a result, Pacific Northwest forests may be unable to meet society's future needs for wood production or ecosystem services.

REVELATIONS OF A TWIG

When it comes to drought resistance, plants have a variety of physiological processes that control vital functions and allow them to survive in dry, hot climates for extended periods. "For Douglas-fir we are looking specifically for answers to questions regarding the broader picture of drought resistance across its range," explains Sheel Bansal, formerly a research ecologist with the PNW Research Station and now a research ecologist with the U.S. Geological Survey. "We want to know from a mechanism-based perspective, by looking at these smaller scale physiological processes, what the morphological traits can tell us about how one population is different from another." Needle length or bark thickness are examples of morphological traits.



Seed sources collected from 35 populations (circles) throughout Washington, Oregon, and northern California and were planted in three common gardens with different climates (stars). Because all the seed sources were planted in a similar environment at each garden, any differences exhibited by the trees are due to genetics or to the interaction between genetics and the environment.

Brad St. Clair, a research geneticist with the PNW Research Station, adds, "We are interested in why certain populations might respond differently, and some of those answers are with respect to adaptive traits, in particular drought and cold. That's why we're looking more closely at the traits related to drought tolerance and cold hardiness."

During the day, trees keep their stomata open so photosynthesis may occur. Stomata are small openings on the surface of the leaves that allow the intake of carbon dioxide and the loss of water vapor during photosynthesis. On hot, dry days, trees will close their stomata to retain water. Although this means sacrificing sugar production, closing the stomata prevents unnecessary water loss. It keeps the xylem stream, which carries water from the roots to

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Brad St. Clair

Brad St. Clair

Researchers collected twig samples from the trees growing at each of the common garden sites. Back at the lab, the twigs were measured to learn their rate of water loss and water storage capacity—characteristics that influence a tree's drought tolerance.

the leaves, from being stretched to the breaking point. When the xylem stream breaks, air bubbles enter in and subsequently interfere with upward water movement. Douglas-fir, Bansal explains, live on the edge, keeping their stomata open as long as possible, at the risk of breaking the xylem stream. Yet even after the stomata close, some water is still lost through leaky stomata and through the waxy cuticle of the needle and twig. This rate of water loss is known as minimum transpiration. Although this is a relatively small amount of water, it may be a critical amount that leads to a break in the xylem stream. Tree species adapted to drought conditions exhibit lower rates of minimum transpiration and thus lose less water under drought stress.

Minimum transpiration can be affected by leaf size. Smaller leaves mean less surface area for water loss to occur. Thicker, smaller leaves are morphological traits of drought-tolerant species. On the flip side, however, smaller leaves also mean less surface area for photosynthesis, which could result in slower growth.

A leaf's capacity to store water also plays a role in enabling a plant to survive drought. Trees that have adapted to growing in drought conditions have cells with greater elasticity, enabling them to store more water when it's available and lose more without being damaged. This flexibility allows the tree to continue growing under dry conditions.

Morphological differences between populations become noticeable when trees from different populations are exposed to stressful conditions, such as drought or cold, that are unlike their current climate. "Most research so far on Douglas-fir has focused on growth and what affects its growth," Bansal says. "Then there's been a lot of research on morphology and cold hardiness, but there's been relatively little research on drought, particularly from a genetics perspective."

To fill in this research gap, researchers designed a reciprocal-transplant common garden study that pushes the suitable climatic envelope for Douglas-fir. "We wanted to see how different seed sources reacted to drought and other stress factors on a range of sites," Harrington explains.

In 2009, two-year old seedlings, representing a sampling of 60 populations of Douglas-fir across the coastal region, were planted in nine sites with different environmental conditions in Oregon and Washington. Of these, 35 populations at three sites were used to assess drought tolerance. This enabled the scientists to later tease out genetic variation from differences in the environment.

"We are looking at genetic variation and separating it from environmental variation," says St. Clair. "A common garden approach allows us to do this because all trees growing at that site are experiencing the same, common environment. Any differences that emerge are due to genetics. Having multiple common gardens at sites with contrasting environments let us test the plasticity of populations to environmental conditions," he explains. A common garden approach also sets the foundation for a long-term study in which trees can be evaluated over many years. Planted in the ground, the trees develop a different kind of a root system than would occur if they were grown in pots in a greenhouse.

Three years later, the researchers visited three of the common garden research sites: a low-elevation warm, dry site located in southern Oregon; a cool, moist site in the Washington Cascades; and an intermediate site in southwest Washington. At each of these sites, the researchers collected two twig samples from four trees belonging to each of 35 populations.

Connie Harrington

Adaptable Douglas-fir: These twigs come from the same seed source but from trees grown in garden sites with different environmental conditions. The stout twig on the left grew at a site with hot, dry summers. Its thick needles have low minimum transpiration rates, which helps the tree conserve water. The twig on the right grew at a site with cool, moist summers. Its thinner needles have higher minimum transpiration rates.

On the south side of each tree, midway up the tree, researchers clipped 3-inch twigs. The twigs were bagged to prevent water loss and then taken back to the research lab.

"To tease out the morphological differences among these nearly 2,000 twigs required quite a bit of time-consuming work," Harrington says. Each twig in the pair was subjected to different measurements. One was used to determine its rate of minimum transpiration. Researchers did this by sealing the cut end with wax and then exposing it to a warm, lighted area. It was weighed every 24 hours for seven days to see how it quickly it lost water.

The other twig in the pair was used to calculate water storage capacity. It was weighed and placed in water for six days to become fully hydrated. The hydrated twig was then weighed, dried, and reweighed. The final measurements required plucking eight needles from both twigs and laying them on tape to prevent curling. The needles were then photographed, and from the photographs, researchers calculated the specific leaf area (leaf area per unit of leaf mass) of the needles.

These measurements would reveal if there were differences between the 35 populations and the three common garden sites, or if there was an interaction between the genetic and environmental conditions. Because the populations originated in different regions, the researchers tested whether the climate conditions of the seed sources could help explain the factors related to adaption. When it came to the data analysis, Bansal says, "It was exciting to be able to analyze such a robust data set because of its comprehensive experimental design and with so many populations in the same environmental conditions."

The results were surprising, yet explain why Douglas-fir is successfully grown around the world.

PROBING A POPULATION'S POTENTIAL

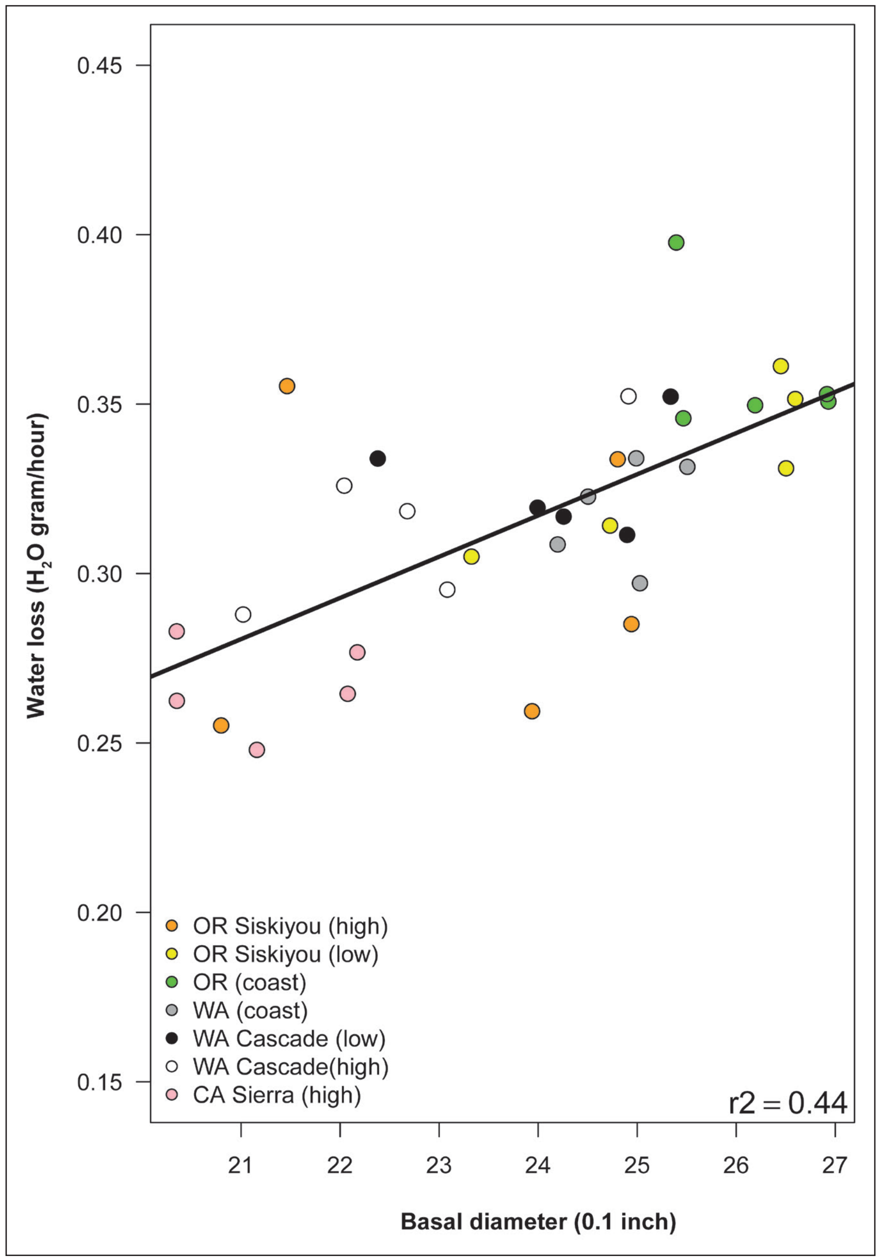
"We found that there is a strong environmental effect on Douglas-fir's drought resistance," Bansal explains. "When Douglas-firs, regardless of where they are from, are exposed to droughty conditions, they can acclimate. They adjust so they have lower minimum transpiration. This shows that Douglas-fir has a lot of plasticity and responsiveness to the environment."

Douglas-fir's adaptation manifests itself with certain populations being better suited to drought conditions than others. "We assumed that populations from the warmest, driest climate would have the greatest drought resistance, but instead we found that populations from areas with the coldest winters *and* driest summers had the greatest drought resistance," Bansal said.

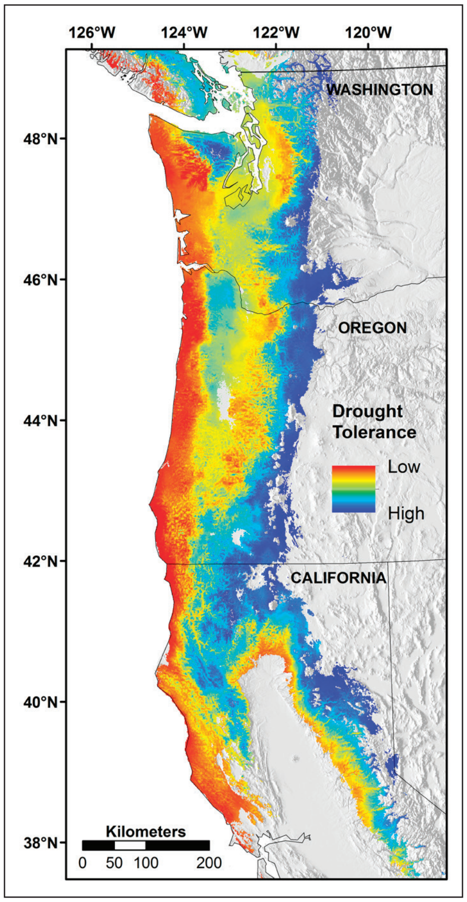
In hindsight, this finding makes sense, Harrington explains, because "the same physiological processes that are beneficial in tolerating winter stress (such as dry winter winds and frozen soils) are also beneficial for tolerating summer drought stress."

The researchers also found that populations from high elevations, regardless of whether it was from a dry or wet site, also exhibit high drought resistance. St. Clair says, "One of the implications of this finding is that if drought becomes a problem with climate change, it won't be as much of an issue at these high-elevations site as we might have thought it would be."

Through Bansal's analysis, he developed a model to predict which populations are best adapted to warmer, drier conditions. This kind of information can be used by tree improvement programs to screen existing populations for drought resistance.



The ability to survive stressful conditions such as drought and cold generally come at the expense of growth rate. However, scientists found some populations of Douglas-fir that had fairly high resistance to these stressful condition, as well as high growth rates. This kind of information can be used to identify nursery stock for tree improvement programs.



Douglas-fir populations whose seed sources came from areas with cold winters—such as the northeast portion of the Olympic Peninsula, the crest of the Cascade Mountains or the Sierra Nevada Mountains—had the greatest drought tolerance.

This is welcome news for land managers, foresters, and geneticists who are working to ensure that Douglas-fir remains a prominent fixture within the Pacific Northwest landscape. "This study is useful both for demonstrating some practical measures of drought resistance that could be incorporated into our operational testing programs and also for providing insight into where to look for seed sources that might be especially tolerant of drought," DeBell says.

This type of study, with its multiple test sites, the length of time required, and intensive data sampling, requires substantial investment. The findings, however, will help guide management of future forests in the Pacific Northwest. DeBell sees the value in extending the study into small-scale operational trials that confirm the results at more sites across the region: "When making management decisions, such as which seed source to plant, that affect thousands of acres a year, we would like that decision to be informed by additional studies such as this."

LAND MANAGEMENT IMPLICATIONS

- By measuring an individual tree's minimum transpiration rate, water deficit, and specific leaf area, tree improvement programs can identify nursery stock that exhibits relatively high drought tolerance.
- Models relating drought tolerance to the climates of seed sources may be used to predict which populations are naturally more resistant to drought stress.
- With this information, land managers can plant seedlings that will be adapted to current and future climate conditions. For example, populations that are more tolerant of drought stress can be planted in drought-prone areas.

Although it is encouraging to know that Douglas-fir forests will acclimate to a warmer climate, in some regions, this increased drought tolerance may come at the expense of a relatively fast growth rate that is prized by land managers. "We found that populations could have good growth and reasonable drought resistance, or reasonable growth and good drought resistance. You can't have both maximum growth *and* maximum drought resistance," Bansal explains.

"If we think the climate will be different in the future than it has been in the past, then we need to do these types of mechanistic studies to understand how they respond to different environments," Harrington says. "By having multiple tests sites and multiple populations and studying several different mechanistic processes, we hope we can do a better job of predicating what could happen in the future."

"Man's yesterday may ne'er be like his morrow; Nought may endure but Mutability."
—Percy Bysshe Shelley, Mutability

FOR FURTHER READING

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