Rangewide analysis reveals climatic sensitivities and non-timber values of tall redwoods

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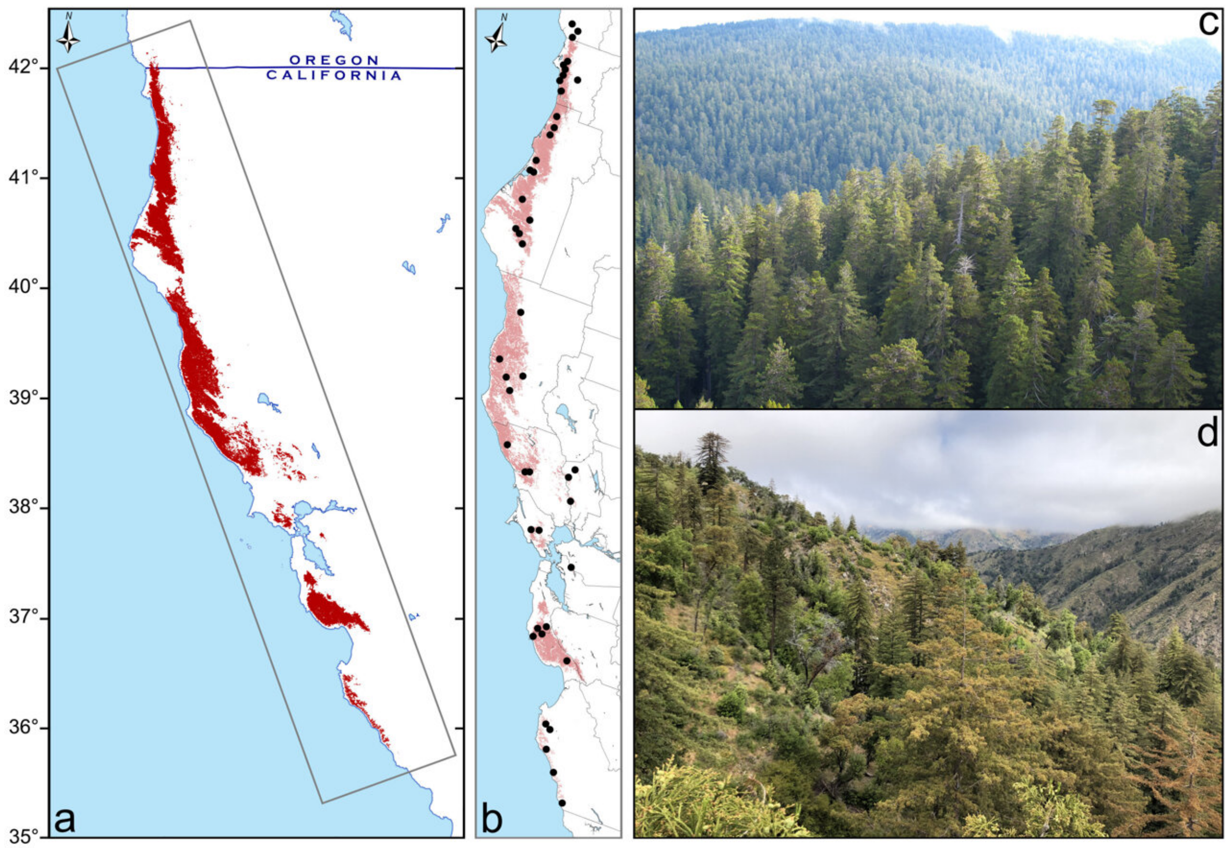

Redwoods span more than 6 degrees latitude (a), and our 45 study locations (b) extend from northern rainforests receiving more than 80 inches of annual precipitation (c) to southern gallery forests receiving less than 30 inches (d). Credit: S. Sillett

Coastal redwood (Sequoia sempervirens) has a narrow and fragmented distribution in western North America. Extreme resistance to fire and fungi allows redwoods to live more than 2,000 years and become the tallest trees on Earth. These same qualities make excellent lumber, and redwoods have been heavily exploited. Less than 5% of primary forests remain, and mature secondary forests are even scarcer due to repeated logging. Non-timber values like long-term carbon sequestration and biodiversity warrant closer consideration in this era of environmental disruption. How might redwoods fare in a changing climate, and what can we do to help?

To answer these questions, we visited 45 locations (32 primary and 13 secondary forests) spanning the species range and climbed 235 trees, measuring each one from base to top and core-sampling trunks at regular height intervals. Redwoods, like other trees, accumulate wood in annual rings. We sampled 1.2 million rings, combined these with intensive measurements and allometric equations to reconstruct tree size through time, and modeled tree performance as functions of landscape position and climate. Our results, published in *Forest Ecology and Management*, are both concerning and hopeful.

Redwoods depend on soil water replenished through precipitation as well as foliar uptake. Rain and summer fog are highest in the north and lowest in the south. The climatic factor most influencing growth is a drought index. Redwoods north of 40° are least drought-sensitive, producing similar biomass in dry and wet years, while trees south of 37° are most sensitive and show less post-drought recovery than northern trees. Since 2020, the entire range is once again experiencing a multi-year drought.

Even without changes in precipitation, the redwood range is drying due to warming. The drying power of air—vapor pressure deficit (VPD)—increases exponentially with temperature. High daytime VPD means trees need to close their leaf stomata earlier to prevent damaging water loss. This limits photosynthesis, but such "source limitation" is mitigated by rising atmospheric carbon dioxide levels. While extreme daytime temperatures can lead to treetop dieback, another temperature effect inhibits tree radial growth.

Growing season nights are become unusually warm. High nocturnal VPD creates a problem in the layer of dividing cells beneath bark—low turgor pressure inhibits cell division and enlargement. With this "sink limitation" too few cells are produced to make new wood, so sugars created by leaf photosynthesis have to be used elsewhere. Where? Roots are one possibility, though the belowground biology of redwood remains largely unexplored. Another major sink is indicated by the name of the tree itself—the heartwood is red because of decay-resistant chemicals. Heartwood fungicide is redwood's superpower.

Trees strike a balance between making new tissues and protecting them from corruption. Sink limitations due to warmer, drier nights may reduce growth but increase durability as excess sugar is used to make fungicide, not wood. Coastal fog helps lower VPD, and nighttime fog is one of the best predictors of redwood growth efficiency. During droughts, redwoods in forests lacking sufficient fog will see the most growth inhibition, but their heartwood may become more durable. This could be a silver lining of climate change—but it's more complicated because all redwoods aren't equal.

A bigger tree makes more wood annually than a smaller tree because it has more leaves, and the older a redwood gets the greater its investment in heartwood defense. Heartwood production and fungicide content are higher in primary than secondary forests throughout the range. This means secondary forests are far less effective than primary forests at long-term carbon sequestration. Considering that 95% of extant forests are young, the priority is clear—we need more big old redwoods on the landscape.

Managing redwoods as short-rotation crops squanders the potential of a species that can live for two millennia. Long-term carbon sequestration is one issue, and biodiversity is another. These two non-timber values are interconnected because decay-resistant heartwood creates durable substrates for epiphytes. Tree structural complexity promotes biodiversity—the largest and oldest trees host the bulk of arboreal life in addition to being carbon-sequestration champions. These "elder trees" are now rare on the landscape, but we can literally grow hope for the future by designating potential elder trees (PETs).

Imagine an approach where some of the most robust trees in a secondary forest are chosen to become part of the long-term inventory. Future land management would promote the health and vigor of the PETs, including thinning of crowded tree neighborhoods. Over time, a decreasing number of enlarging trees would produce increasingly durable biomass with some PETs gaining full stature and becoming elder trees. The PET strategy means wood production and non-timber values aren't mutually exclusive. While the PET idea isn't limited to one species, the extreme size and longevity of redwood make it ideal for this novel approach to forest management.

The variability of redwood forests presents challenges for establishing realistic restoration targets across the range. Where do we start? The PET approach has maximum impact in the northern range because of ecologically important vascular epiphytes. Well-developed epiphyte communities, including ferns, shrubs, and canopy soil, occur only in elder trees of the wettest and foggiest forests. The northern range also holds the most land area of secondary forests with unrealized potential for long-term carbon sequestration. Young redwoods north of 40° have the highest growth efficiency but the lowest investment in heartwood defense. Promoting redwood PETs in the northern range would maximize their future contributions.

A thriving population of PETs across the redwood range would provide non-timber values in perpetuity. Realistically, these iconic trees might become shorter because of extreme daytime temperatures and smaller because of higher nighttime temperatures. Hotter droughts and more frequent wildfires might cause contraction of the species range near its margins. However, with thick fire-resistant bark and an amazing capacity for clonal reproduction, few tree species are so well equipped to persist in an uncertain future. Our actions now determine the quality of forests to be enjoyed by future generations.

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documented in Richard Preston's "The Wild Trees" (2007). Humboldt dendrochronologist, Allyson Carroll, and three other co-authors (Mark Graham, Alana Chin, Bob Van Pelt) were integral to the rangewide analysis of redwood.

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