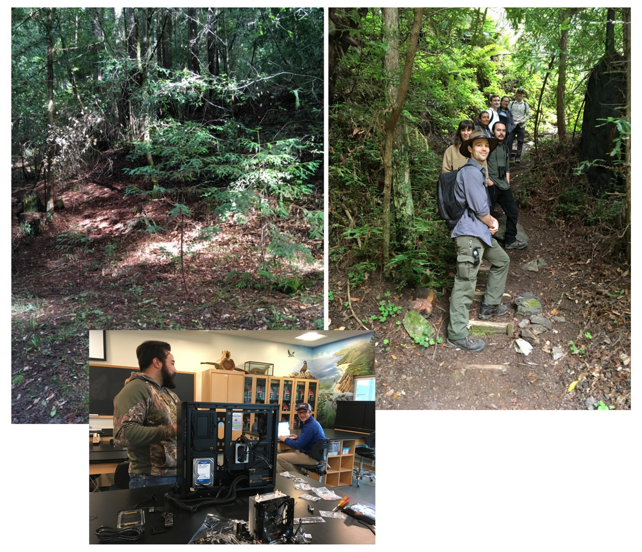

Coast Redwood Seedling Survival Ecology in Extremes of the Species Range

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Abstract

As California's climate changes, patterns of coast redwood (*Sequoia sempervirens*) seedling survival will affect genetic diversity in populations at extremes of the species range. Understanding seedling tolerance of microclimate factors can also help inform restoration efforts and future range predictions.

Climate envelope models for coast redwoods based on climatic water deficit (CWD) do not factor in moisture from fog. Additionally, these models are based on adult distributions and may not reflect factors important for juveniles. Our team is working to create a predictive microclimate envelope model for the "Goldilocks zone" for coast redwood seedlings; we are analyzing data from our different sites and refining our approach to measuring canopy cover.

Introduction

Species ranges are expected to shift with climate change. To predict the future of coast redwoods, we need to take several factors into account. The current range of coast redwood correlates tightly with the summer fog belt (1,2) but recent work suggests that fog frequency has been declining (3). Climate envelope based models have predicted a significant loss of suitable coast redwood habitat (4), but the climatic water deficit calculations used in generating many models do not factor in fog moisture (5). Population health does not depend only on adults: for long term genetic diversity, seedling establishment is also important (6), but the models are based on adult distributions, and there is a poor understanding of redwood seedling ecology (7). Microclimate factors will be critical in determining survival of populations and seedlings under climate change (8,9). Using data from range extremes, we are evaluating what microclimate conditions (temperature, canopy shading, fog effects, and other factors) redwood seedlings survive in so that we can create a better model. We became concerned that our canopy cover measurements were not capturing the necessary complexity, and ran an experiment to test one aspect of this.

Populations in range extremes serve as "climate analogs" representing what may happen to other populations as climate changes; these populations may be sources of genetics that can survive the conditions of the future.

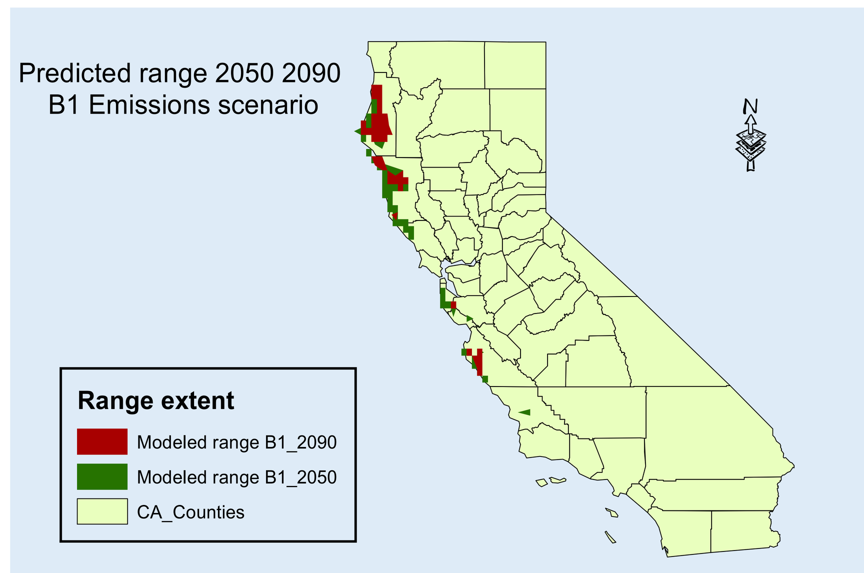


Figure 1: predicted redwood range by 2050 (green) and 2090 (red) under *low emissions* scenario using CWD-based model

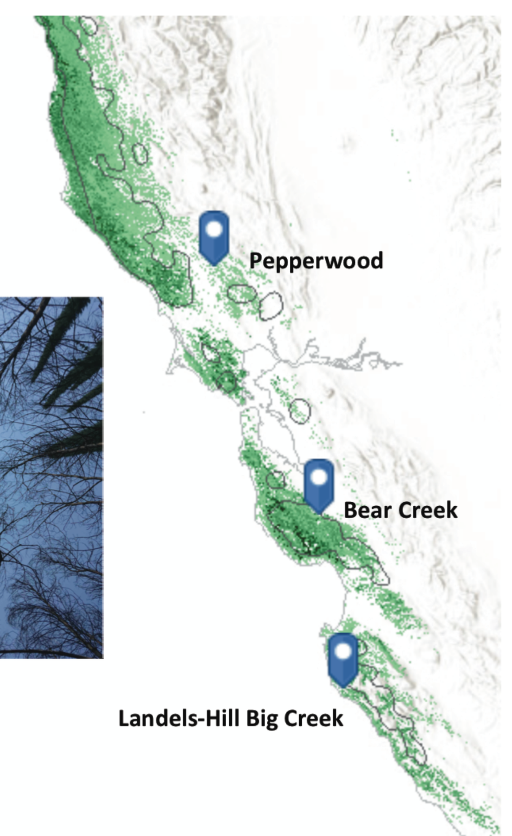


Figure 2: study sites at range extremes; **Photo** shows canopy at Pepperwood Grouse Hill site

Methods

Site selection

Study locations were near southern and central-eastern extremes of the species range; individual redwood stands were chosen with elevational gradients, accessibility, and privacy in mind.

Bear Creek Redwoods: 2nd growth stand on the eastern edge of the Santa Cruz mountains near Saratoga/San Jose

Landels-Hill Big Creek Reserve: old-growth stand near Big Sur

Purisima Creek: 2nd growth stand south of San Francisco

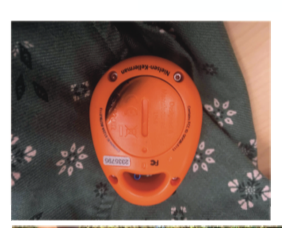
Pepperwood Preserve (Sonoma County):

- **Grouse Hill**: redwood stand,burned to canopy top in 2017 Tubbs Fire
- **Redwood Canyon**: redwood stand that burned to lower/mid-canopy

Dataloggers

We used Kestrel Drop D1 (temperature only) and D2 (T and relative humidity) dataloggers, mounted ½ meter from soil surface in protective radshields (10), measuring every 30 minutes (2018) or every hour (2019) from June-Sept (2018) or June-November (2019).

At each site, three dataloggers were positioned through the elevational gradient of the stand; two were positioned at more open reference points along the same elevation as the two upper elevation mainline dataloggers.



Seedling microclimate evaluation at the extremes of coast redwood's range may help us predict effects of climate change

Seedling survival, in response to temperature, light, and moisture, affects genetic structure of future populations

Near Big Sur, summer temperatures were too cool for optimal growth except near the creek – where saplings were found

At a Sonoma County post-burn site, 2019 seedling recruitment rates were high, but mortality in late summer/early fall was also high – possibly due to low humidity

Canopy cover evaluated simply as percent cover is not sufficient for our analyses

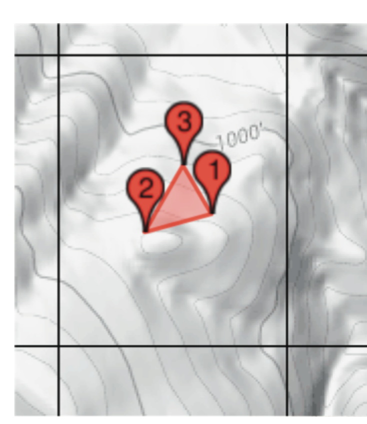
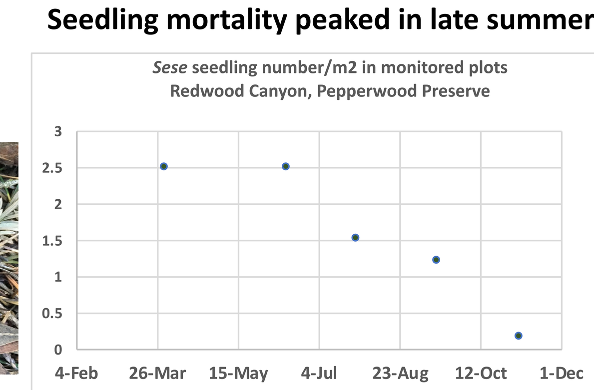


Figure 3: NE-facing redwood stand at Redwood Canyon; **photo** shows a seedling in late July

Seedling mortality peaked in late summer



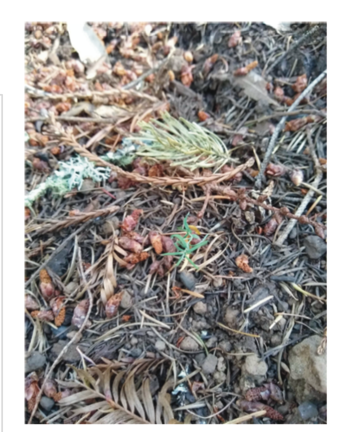


Figure 4: Seedling density in monitored plot summer 2019; **photo** shows a wilted/dying seedling September 15, 2019.

Methods

Seedling/sapling surveys, and monitoring first-year seedlings for survival

We sampled within elevational gradients. At LHBC , PUC & Bear Creek, we used switchbacks and EW trails, stopping every 100 m, and then to the first redwood; on non-switchbacks, samples were at 5 sec longitude, and then to the 1st redwood. At each point, a 6X6 m plot was surveyed upslope and downslope. At Grouse Hill and Redwood Canyon, we ran belt interval transects (1 m wide) on both elevational gradients and running the length of the stand.

Two seedling monitoring plots (3mX1m)were set up at Redwood Canyon in July 2019 to follow seedling mortality across time.

Growth experiment to address canopy cover questions

Seedlings from Sonoma Co. in 1 gal. pots were randomly assigned to full sun, shade (40% shadecloth), N-gap or S-gap (open on one side, 90% shadecloth on the other). All seedlings were watered when any pot felt dry 2 cm deep; heights (distance to the farthest node) were measured, and rotated between blocks of same treatments at monthly May-December 2019.

At Landels-Hill Big Creek near Big Sur, sapling frequency was highest near the creek where temperatures were warmer

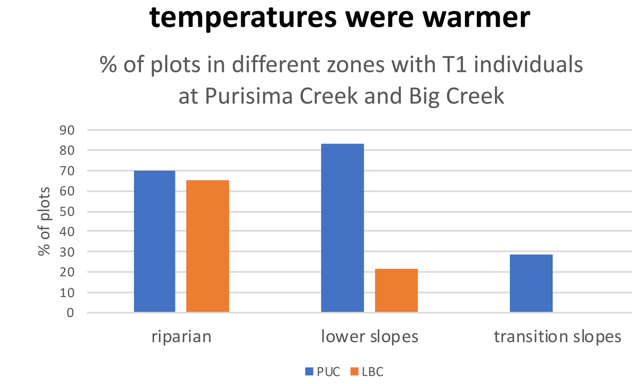


Figure 5: Differences in distribution for small (T1) redwoods in different zones at the moderate site PUC(blue) and southern site LHBC (orange).

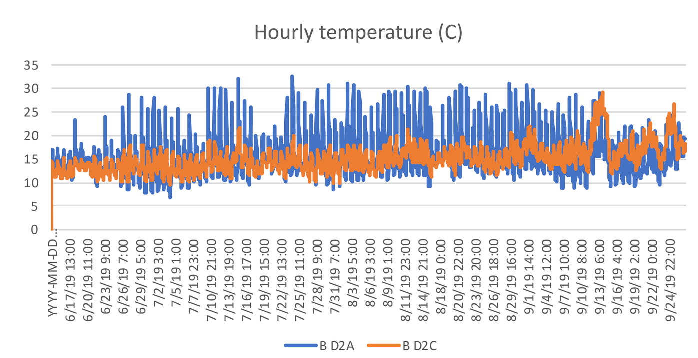


Figure 6: LHBC temperatures: BD2A (**blue**), **near the creek, regularly recorded temperatures at or near coast redwood growth optimum**; higher elevation sites (**orange**, illustrated w BD2C data) were cooler.

In late summer/early fall, humidity levels *stayed* low for prolonged periods at Pepperwood

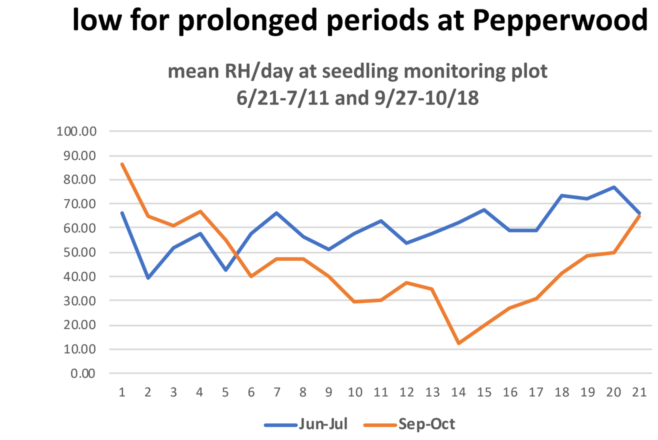


Figure 7: Data from seedling plot. Blue line is mean RH June-July ; orange is mean RH Sep -Oct

Results

Site microclimate highlights

The **Landels Hill-Big Creek** site near Big Sur experienced high humidity and moderate temperatures most of the summer. Along the elevational gradient we saw one significant difference: only the creek-side subsite regularly reached optimal temperatures for seedling growth (**Figure 6**).

At **Redwood Canyon**, in midsummer there were few microclimate differences along the elevational gradient. From June-August, stretches of several days of high temperatures and low humidity were followed by periods of high humidity as fog moved in. However, in September, October and early November, the pattern changed, with prolonged periods of low humidity even though temperatures were also often low (**Figure 7**).

Seedling surveys and monitoring

At **Landels-Hill Big Creek**, saplings were found in high frequency only near the creek (**Figure 5**).

At **Grouse Hill**, there were no redwood seedlings found.

At **Redwood Canyon**, in March 2019 overall we found redwood seedlings at densities >2/m^2, but in clumped distributions; over the course of the summer, most of the monitored seedlings died.

Growth experiment

Seedlings in the shade treatment or in the N-facing gap treatment were taller and had higher growth rates compared to seedlings with a S-facing gap (**Fig.8**) , **although canopy percent cover was the same.** Seedlings in the full sun treatment, although regularly watered, grew less than the shade and N-gap plants and had higher mortality rates (**Photo**).

N-gap seedlings outperformed S-gap seedlings with same percent cover

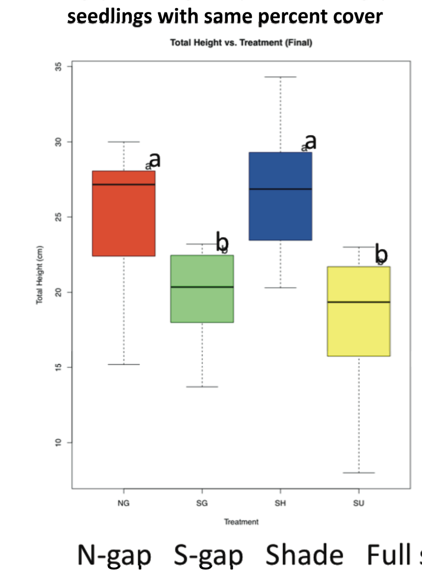


Figure 8: growth experiment testing canopy pattern. Mean total heights measured Dec 7th. ANOVA and Tukey's HSD; different letters indicate p<.05. Pattern was the same for increase in height and percent height increase (data not shown.)

Photo: dying redwood seedling in the full sun exposure treatment.

Preliminary conclusions/next steps

*At Landels-Hill Big Creek, seedling and sapling growth may be limited in much of the canopy by cold temperatures and low levels of sunlight during the summer rather than by drought stress (our original hypothesis).

*Seedling mortality at Redwood Canyon was not especially high in spring and early summer – the pattern of high temperature days draining in fog may help explain this. However, in Sept-Oct, periods of low humidity that were not quickly relieved by fog influx may be responsible for increased seedling mortality. If *future* fall weather in California is dry, or hot and dry, seedling establishment at sites like Pepperwood may become increasingly unlikely.

*Gaps of the same size are not the same - north-facing redwood seedlings with same percent cover/daily light integral as south-facing ones outperformed them. We are refining our methods to capture both gap pattern and topographic effects more quantitatively.

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More detail: