METER
ENVIRONMENT

WHAT PLANT HYDRAULICS TELL US ABOUT DROUGHT RESPONSE

Trees are merchants; they sell water to the atmosphere in exchange for the CO_2 they need to photosynthesize sugars. The exchange rate or 'water-use efficiency' that drives the plant carbon-water market place is a function of atmospheric CO_2 concentrations. Thus, theoretically human carbon emissions, which have increased atmospheric CO_2 by 40% since 1850, should increase plant water use efficiency, resulting in "CO_2 fertilization" of our forests and crops.

However, evidence for CO_2 fertilization is extremely mixed. That's why Leander Anderegg, postdoctoral fellow at UC Berkeley, and his research team are performing a two-step experiment to determine if increased atmospheric CO_2 conditions increase plant water-use efficiency. The team is leveraging a natural elevation gradient in temperature, vapor pressure deficit, and precipitation on a southwestern Colorado mountain to understand:

1. How much physiological variation is on a single mountain slope between two species

2. How that variation ultimately affects the potential for CO_2 fertilization and differential vegetation responses to rising CO_2

For five years, the team has worked on quantifying how two tree species (Ponderosa Pine and Trembling Aspen) can shift their physiology going from low elevation (hot, high vapor pressure deficit environments) up to high elevation (wet, cooler, low vapor pressure deficit environments). They want to understand what that means for each species' water relations, drought vulnerability, and biogeography in a drying and warming climate.

QUANTIFYING WEATHER PARAMETERS

Anderegg and his team use METER ATMOS 41 weather stations to quantify exactly how much the local environment changes from the bottom to the top of the mountain. Anderegg says he's been surprised at how influential vapor pressure deficit changes are on the tree species. He says, "When we compare Aspens to

Ponderosas, we've found that the difference in atmospheric demand is a big part of the story, particularly in how they respond to drought stress. There is more atmospheric demand at the bottom of the mountain. So one key objective was to quantify how much drier the air was during the peak mid-summer dry down for most of the species. This was critical then to infer how stomata were responding to that gradient and water stress. It's really difficult in these wide field plots to actually measure transpiration. But with physiological measurements of leaf water potential, hydraulic conductivity, and the vapor pressure deficit from relative humidity sensors, we could then infer how open the stomata were."

Anderegg used a pressure chamber to measure leaf water potential and also did a lot of shotgun sampling to measure the hydraulic conductivity in twigs. He describes the process, "I went out at 3 am with a 20 gauge shotgun loaded with birdshot to shoot off branches. We pulled water through the branches by applying a vacuum to a pressure chamber and then inserting one end of the branch. To get the hydraulic conductivity of the branch, we measured how quickly the water moved into the chamber." (Kolb et al 1996)

VAPOR PRESSURE DEFICIT WAS SURPRISING

Anderegg says vapor pressure deficit changes across the elevation gradient were much stronger than he expected. He says, "It was pretty impressive that as you drove up this elevation gradient, the vapor pressure deficit differed by approximately 1.5 kPa. In the crop realm, a vapor pressure deficit of 2 kPa is pretty intense, but we went from a bit over 1 kPa near the top of the mountain to more like 3 kPa down at the drier bottom, which translates to a remarkably different water-use efficiency.

TWO SPECIES—TWO ADAPTATION STRATEGIES

When asked what they've learned, Anderegg says the difference between the two tree species is pretty amazing. "We've seen that the two species have extremely different responses to drought stress. Aspen keeps its stomata open, even at the bottom of the mountain where it's really dry. It just alters its hydraulic system to try and keep up with it. The Ponderosa, however, does not alter its hydraulic system. It just closes its stomata until it rains in the fall."

Anderegg adds that the two different water relations strategies line up with the type of biogeographical shifts occurring in the two species as the Southwest dries out. He says, "Aspen is sort of a 'grin-and-bear-it' species that toughs out drought while Ponderosa is a 'sit it out' sort of species. For the last 15 years, the Aspen have been creeping uphill but not gradually. Intermittent droughts are slowly trimming the driest Aspen up the hill in fits and starts. Ponderosa are better at dealing with extreme droughts because they preserve their hydraulic systems. We have not seen mortality pushing the Ponderosa uphill. However, there's essentially no Ponderosa recruitment (new tree starts) at the bottom of the hill, and the growth rates of adults are a quarter of the rates at the top of the hill. So we think the Ponderosa will move uphill following mean climate change and not in fits and starts. They'll gradually die off at the bottom and not be replaced by young recruits which will cause them to move uphill in a more gradual manner."

TRANSITIONING TOWARD THE FUTURE

In the years ahead, Anderegg hopes to move into the second phase of the experiment: testing how these two species will respond to CO_2 fertilization. He says, "We need to make these measurements over multiple years and many environmental conditions to start to get at how much plasticity any individual plant can manifest (plasticity is the amount that a plant can change its physiology in response to climate change. So if this condition happened, how likely is the plant to respond in a particular way over time) and what the long term trajectories are in these hydraulic traits. We've gotten measurements at the height of a significant drought and then another medium year following that drought. We want to transition toward a long-term monitoring perspective that hopefully will give us the information we need to start thinking about how CO_2 then plays in."

You can learn more about Leander Anderegg's research here: ldlanderegg.com

REFERENCE:

Kolb KJ, Sperry JS, Lamont BB (1996) A method for measuring xylem hydraulic conductance and embolism in entire root and shoot systems. Journal of Experimental Botany. 47:304, pg 1805-1810