The final gasp: Pinyon pines die faster during warmer droughts

By Zack Guido

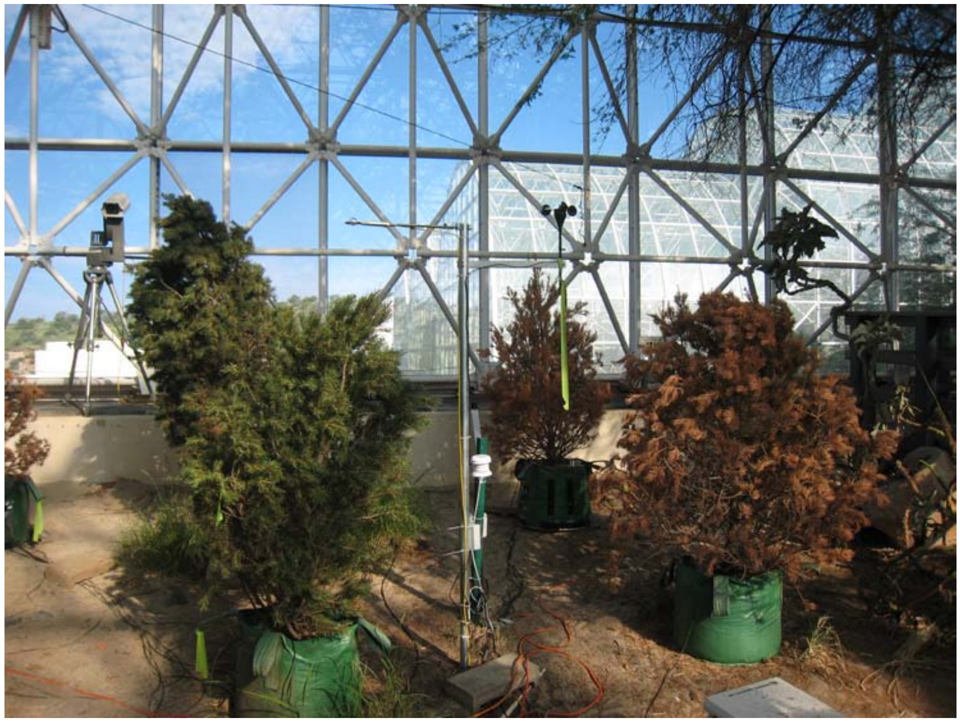

Figure 1. Adams monitored watered and unwatered trees in two temperature environments—one similar to current summer temperatures and one about 7 degrees F warmer. The experiment was conducted at Biosphere 2 located in Oracle, Ariz. Figure courtesy of Henry Adams.

Trees are hearty, but they have their limits. Ask Henry Adams what it takes to kill a pinyon pine, and he smiles and his eyes light up as he explains that in experimental conditions, pinyons can survive for around 26 weeks without water, but higher temperatures cause them to wither faster. For the past three years he has been conducting elaborate experiments in Biosphere 2 near Oracle, Ariz., and more recently in Flagstaff, Ariz., to see how water-starved trees fair when subjected to two different types of conditions: current summer temperatures in the Southwest and warmer temperatures that global models project for the region by the end of this century.

Adams, a PhD candidate in the School of Natural Resources and the Environment at the University of Arizona, is measuring the physical changes in withering trees to understand the causes of large forest die-offs that many western states have been experiencing. In recent years hot sun and bone-dry air have contributed to massive die-offs in the West that have affected nearly 80,000 square miles—about two-thirds the size of Arizona—including about 4,500 square miles of pinyon forests in the Four Corners region during 2002–2003. These once vibrant groves have been turned into tinder, posing a fire risk and denuding the landscape of colorful fall foliage that attracts tourists.

Understanding how trees die and the role temperature plays in expediting tree mortality has profound implications for the Southwest and beyond, particularly because droughts are projected to be longer, more frequent, and warmer, according to the latest United Nations Intergovernmental Panel on Climate Change (IPCC) report published in 2007. Enter Adams and his latest research, co-authored by several other UA researchers, which quantified how increased temperatures during droughts accelerate die-offs.

In a March 31 interview with Zack Guido, CLIMAS staff scientist, Adams discussed his research results. His findings were published in the September 22 issue of the *Proceedings of the National Academy of Sciences* in the article, "Temperature Sensitivity of Drought-induced Tree Mortality Portends Increased Regional Die-off Under Global Change-type Drought."

Question: What questions did you set out to answer in your research?
Henry Adams: We wanted to investigate if the observed elevated temperatures during the drought in 2002–2003 could have caused the pinyon tree die-off around the Four Corners region. There have been a bunch of studies that say the die-off is associated with a warmer drought, but we wanted to say that the die-off is caused by the elevated temperatures during the drought.

Q: How did you test the effects of temperature on tree mortality?
HA: We subjected the trees to two different temperature treatments while not giving them any water. Five trees were in a temperature environment that mimicked summer temperatures here in the Southwest, maintaining daily fluctuations. Another four trees were placed in a room that experienced about a 7-degree Fahrenheit (approximately 4 degrees Celsius) increase, again maintaining daily fluctuations. Each of the different environments had five control trees that were watered.

The trees were immediately aware that we had shut off the water valve. By about week three, the unwatered trees in both experiments were not using moisture in the soil, they were saving it. They were waiting out the drought, and we were going to outwait them.

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Q: How did you set up the experiment?
HA: We trucked 50 pinyon trees from northern New Mexico to the Biosphere 2. The trees were about eight-feet tall and were several years old but were considered mature pinyons. They were planted in large sacks (Figure 1). We couldn't ship the soil from New Mexico so I had to make soil here, getting the organic content and chemistry of the soil as similar to the original make-up as possible. Once they were transplanted to Biosphere 2, we waited about seven months before beginning the experiment to make sure the trees survived the move. All but 10 did. In one room, we cranked up the temperature [to reflect the IPCC projections]. In the other room we maintained ambient conditions. The Biosphere gave us very good control over the environment.

During the experiment we measured the soil water content. We had three trees in each temperature environment on scales so we could see soil moisture changes—[as the trees use water the total weight of the tree decreases]. We also measured photosynthesis and respiration of the trees, among other things.

Q: Why did you choose to study pinyon pines?
HA: During the drought in 2002–2003, pinyon trees died all across the region while other species, like ponderosa pine, Douglas-fir, and aspen were mostly getting hit on the lower elevation ends of their ranges where they encountered the driest conditions. But pinyon pines were dying all through their elevation ranges, even at the moister sites, which was unusual and not what you would expect. It looked like a population crash. It made us wonder why the trees growing in choice sites were dying.

We also chose pinyon pines because they are fairly small when they are mature. If you want to do this study with a lodgepole or ponderosa pine, the big trees, you would have to study the sapling stage, which is morphologically less similar to full-size trees.

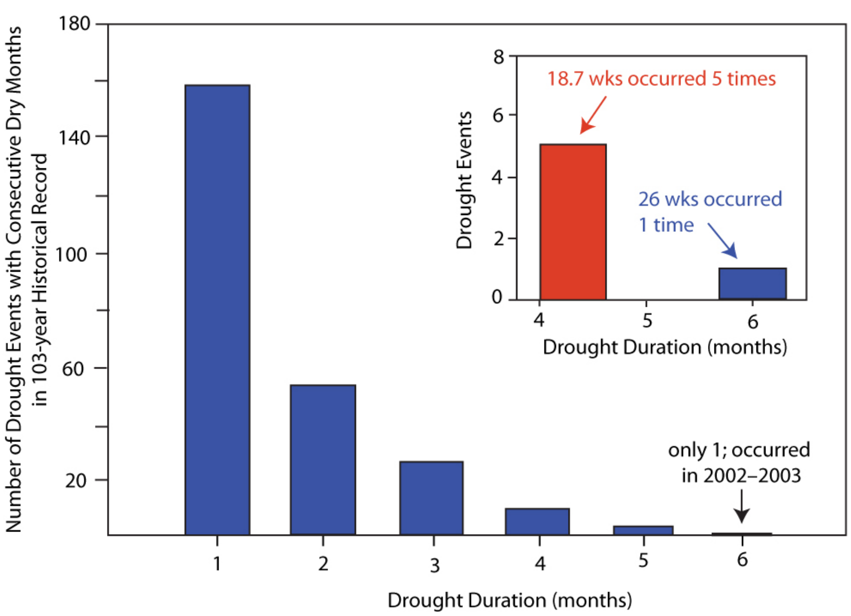

Figure 2. Shorter droughts are more common than longer ones. In the last 103 years, only the 2002–2003 drought lasted 26 weeks or longer, while five droughts were equal to or longer than 18.7 weeks. Since the results of the experiment suggest trees in warmer climes die faster than trees in cooler temperatures, a warmer future could cause more massive die-offs. Figure courtesy of Henry Adams.

Q: How long did it take to kill the trees?
HA: On average the trees in the warmer environment died in 18.7 weeks, while the trees in the ambient temperatures died in 26.1 weeks. This is a 28 percent difference. All the trees in the warmer temperatures died between about week 16 and 20 and all before the first death in the ambient conditions.

Q: What did you observe while the trees were dying?
HA: When they were getting close to dying, the skin of the bark was shriveling. I remember touching it and thinking it felt like loose skin. We told everyone working on the project not to touch the trees because the bark could rip apart and we wanted them to die naturally.

The trees were probably shrinking a bit as they dried out, too. Their foliage would first turn light green and then from light green to brown in about a week. After that, boom, they died fast. One week you might see about 50 percent brown needles. The next week there would not be a spot of green on them. When the trees were 90 percent brown we called them dead. Just to make sure, we turned the irrigation back on to see if they could recover. They didn't.

Q: How did the trees die?
HA: We were really hoping to observe the death rattle of the trees, a final gasp where the trees let loose the little bit of water they've been holding back. We didn't hear that. But, our data suggest that the trees in both temperature conditions died from carbon starvation.

[Carbon starvation occurs when trees close their pores, called stomata, to prevent water loss.] Stomata allow trees to inhale and exhale. They take in carbon dioxide, which they basically build their food out of, and they let out oxygen and water in a process called transpiration. During drought some trees maintain open stomata to continue to suck up carbon,

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while others close them to prevent moisture loss. There's a trade-off in doing either.

Our measurements show that photosynthesis drops to zero by about week five—so no carbon coming in—and respiration rates were greater than zero and were slightly higher in the warmer ambient temperatures. Even when trees stop transpiring they still use carbon. So each week their carbon reserves were getting smaller and smaller, and the warmer drought trees were burning through their carbon stores faster. This makes sense. It is well understood in biology that respiration rates are tied to temperature. Think about two people running a marathon in the summer. If you give them the same pasta dinner the night before, the person running in Chicago will have an easier time than the runner in Tucson when its 100 degrees F. Just before their death, on average, the trees had respired the same amount, even though the trees in the warmer drought conditions died about seven weeks sooner.

Q: Why did you choose 7 degrees Fahrenheit?
HA: About 7 degrees F is a mean estimate for the temperature scenario from the IPCC projections for 2100. It's also become standard for research looking into the effects of temperature, which makes it easier to compare results between studies. Also, 7 degrees F is a big enough change to show that there is a difference between ambient temperatures and the warmer scenario.

Q: Would there have been more die-offs if the past was warmer? In other words, will die-offs increase in a warmer future?
HA: In our experiment, when we cranked up the temperatures [about 7 degrees F], we found that it took about 28 percent less time to kill pinyons. What does this mean for a warmer future? It means that shorter droughts will become sufficient to kill trees, and there are more frequent shorter droughts than longer ones. We quantified this in our paper. Looking at the historical record, the drought that caused the 2002-2003 die-off lasted six months around the region and was the longest drought in the entire record. However, there were five droughts in the last 103 years that were 28 percent shorter (Figure 2). This could imply that a warmer future could have five times more die-offs.

Q: Why is this important for the Southwest?
HA: There are consequences of a warmer world and we are trying to show that. In the Southwest, pinyons aren't worth much and they don't even make good firewood. But in British Columbia, a regional die-off affecting about 50,200 square miles is starting to nail their timber industry. We looked at one species, but it's reasonable to think temperatures will impact others in similar ways.

Carbon sequestration is also impacted. People are counting on the biosphere to take up anthropogenic carbon dioxide, and it's been doing that. But the die-off in British Columbia is causing all that carbon sequestered in the trees to flow back into the atmosphere. What happens if a die-off occurs in the Amazon, [a major global sink of carbon dioxide]?

There are other implications for hydrology that are just starting to be explored. What does this mean for how much water is available in reservoirs? Will die-offs increase or decrease streamflow? People are studying this now.

Q: What are your next steps?
HA: We are currently repeating the experiment outside in Flagstaff. We have transplanted pinyon pines from a source location to a lower elevation, which equates to a warmer climate. These trees are not put in sacks but planted back into the ground. We have also transplanted pinyons from the same source location across the site, keeping them at the same elevation to compare transplanted trees at both locations. So far the temperature difference between the two areas has been about 6 degrees F (or 3.5 degrees C) on average. We are simulating drought by putting big tarps beneath the branches so they get full sunlight, but most of the water runs off to the side and away from the roots.

The idea is to repeat the experiment in an environment with realistic conditions. The problem with the Biosphere study is we don't want people to take the absolute survival time and apply it to wild trees. That's not correct. The trees planted in sacks survived for 26 weeks without water under ambient conditions, but trees in the ground should last longer. The downside is we are sacrificing control [in the Flagstaff experiment]; we don't know what our temperature treatments are going to look like.

We started simulating drought last September and the soil moisture has recently begun to decline, but we don't have any preliminary results yet. We think the 28 percent difference in the time it takes to kill trees between the two environments with different temperature will hold up. Publishable results will likely take a few years.