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Among the expected impacts of elevated atmospheric CO₂ on tree growth is an increase in the efficiency of water use by trees as part of the photosynthetic process. This increase in water-use efficiency (WUE) comes about through the effect of CO₂ on stomatal aperture and resulting water loss through transpiration. With higher atmospheric concentrations of CO₂ available for photosynthesis, the stomates of trees do not have to open as wide to maintain a sufficient concentration of internal leaf CO₂ for a given rate of carbon fixation.

Since transpiration rate is related in a major way to the degree of stomatal opening, less water is lost through transpiration per unit carbon fixed. This interaction between external CO₂ concentration, stomatal aperture, and transpiration rate is known to exist experimentally, and it ought to result in increased growth (i.e. wider ring widths) in trees photosynthesizing in moisture-limited environments. Yet, this latter effect has been extremely hard to document in tree rings through ring-width analyses alone. Some success has been made in detecting a WUE signal in the $\delta^{13}\text{C}$ ratios of tree rings from arid-site conifers in western North America. However, this is an expensive and time-consuming process, which necessarily limits its application across space and time.

A map of the western United States showing state boundaries. The Great Basin region is shaded in gray and labeled 'Great Basin'. Within this region, in southern Nevada, is a black square icon labeled 'Great Basin National Park'.

Playas are a conspicuous part of this desert, due to its recent geological activity. In notable contrast to the other three deserts, Great Basin vegetation is low and homogeneous, often with a single dominant species of bush for miles. Typical shrubs are Big Sagebrush, Blackbrush, Shadscale, Mormon-tea and greasewood. There are only occasional yuccas and very few cactus.

Because the park's forest covers a large range, from lower-forest border to upper-timberline, it supports eight arid-site conifer species at a number of elevations (see Table 1). These species are certain to be drought-stressed on a routine basis. This diversity of species and elevation range limits will allow us to determine if certain species/elevation combinations are optimal for detecting a WUE signal. If a WUE signal can be found in any tree-ring series anywhere, it ought to be found in some or all of these arid-site conifers in the Great Basin National Park.

[illegible]

The tree was named "Prometheus" and recognized by many, prior to 1966, as possibly older than its California cousins. In 1966 a young graduate student from North Carolina, studying east central Nevada's, Snake Range for long climate records from trees, cut down Prometheus.

Some say, he got his borer stuck in the tree and couldn't remove it, some say he just wanted to get the tree's total age? Whatever the reason, the lesson learned, from this sad moment in dendrochronology's history, is regrettable. Today dendrochronologists rarely use a chain-

saw to collect samples unless the trees they are sampling are already dead. Below are two recent photographs taken from the site on which Prometheus stood. On the left is a portion of an internal scar left from some early sampling with an increment borer. On the right, is a photograph of what is left of the world's once oldest, living, inhabitant.



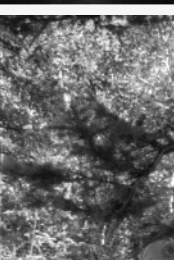
Common Name	Scientific Name	Elevation (ft)
Utah juniper	<i>Juniperus osteosperma</i>	3,000-8,000
Single leaf pinyon pine	<i>Pinus monophylla</i>	5,000-9,000
Ponderosa pine	<i>Pinus ponderosa</i>	7,000-8,500
Douglas fir	<i>Pseudotsuga menziesii</i>	6,500-9,000
White fir	<i>Abies concolor</i>	7,000-9,500
Englemann spruce	<i>Picea engelmannii</i>	7,500-timberline
Limber pine	<i>Pinus flexilis</i>	8,000-timberline
Bristlecone pine	<i>Pinus longaeva</i>	9,000-11,500

At each sampling point an estimate of stand density and composition was made using standard forest silvicultural methods. Two cohorts of trees of a given species will be randomly sampled (20 trees/cohort) to test whether there is an age-related bias in drought sensitivity and WUE. These cohorts will be roughly in the <100 and >100 year age classes, but will ultimately be selected by diameter class in the field. This design will provide a full sample of nine tree species by elevation and cohort for a total of 54 annual tree-ring chronologies for analysis. This collection ought to provide an adequate basis for detecting a WUE signal if it exists.

We expect drought sensitivity to decrease with increasing elevation for a given species. This would occur because of adiabatic cooling, lower transpiration demand, and increasing precipitation with elevation. However, it is unclear that WUE will similarly decrease with increasing elevation for a given species. This is because pCO₂, which helps control stomatal aperture, also decreases with elevation. So it is possible that WUE will change less with elevation. Determining the correct answer to this puzzle in the tree rings would be an important outcome of our study. Using multiple tree species is also important here in determining the consistency of our findings. We might expect that each species growing at its lower elevation limit will be similarly drought stressed, even though several of the species in Table 1 have different lower elevation range limits. So, there is an element of redundancy built into this experimental design for detecting a WUE signal.

We also expect the strength of the WUE signal to increase with time consistent with the non-linear, monotonic increase in atmospheric CO₂, especially since 1950. However, it is not clear at this time how the WUE signal will manifest itself in the ring widths. For example, there may be a change in the relationship between rainfall/drought and ring width due to a general decline in the number of physiological drought days (as opposed to the number of climatological drought days) per growing season. As such, ring width may increase in a continually diverging way from what climate predicts, with both ring-width minima and maxima showing comparable or proportional increases. If this model is correct, then it implies that the Law of Limiting Factors, as applied to internal moisture stress, is operating in the linear portion of its range because the full range of ring width is benefiting from increasing WUE. Another possibility is that the response to WUE will manifest itself more in a one-sided sense, with its effect showing up more strongly in the drier years when moisture stress is most limiting to growth. As such, wide rings may not reflect increasing WUE as much as narrow rings because wet years already provide adequate moisture for growth. This model implies that the Law of Limiting Factors is operating in the non-linear portion of its range, with ring-width minima becoming systematically larger with increasing WUE and little or no change in ring-width maxima. Both of these models will need to be tested.

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1.) Coring Pinyon pine at the lower forest border and taking a GPS reading to record the samples location. 2.) Coring Engelman spruce at 9400 ft. 3.) "This one's really old?" 4.) "OK, it's June 10th right? What's with the snow? and who left the kitchen door open again?"

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Aside from the great collection of arid-site conifers to sample, Great Basin National Park would appear to be ideal for this project in another way. There has been much debate about the possible fertilization of tree growth by chronic nitrogen deposition (NO_3^- and NH_4^+ in particular) from anthropogenic sources. If this effect were present in the ring widths, then it would be a devastating confounding variable to disentangle from the putative WUE signal. Great Basin National Park has been a National Atmospheric Deposition Program/National Trends Network (NADP/NTN) monitoring site since 1985 (see <http://nadp.sws.uiuc.edu/nadpdata/siteinfo.asp?id=NV05&net=NADP>). Maps of NO_3^- and NH_4^+ deposition across the US show that this location is near the US national minimum on an annual basis. Over the period 1985–1998, the median deposition of NO_3^- and NH_4^+ was only 3.26 and 0.71 kg/ha, respectively. It is unlikely that this level of “fertilization” would have a significant effect on tree growth in our study region.

