

# Modeling radial growth in *Pinus edulis*: the effects of CO<sub>2</sub> and prior years

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## Abstract

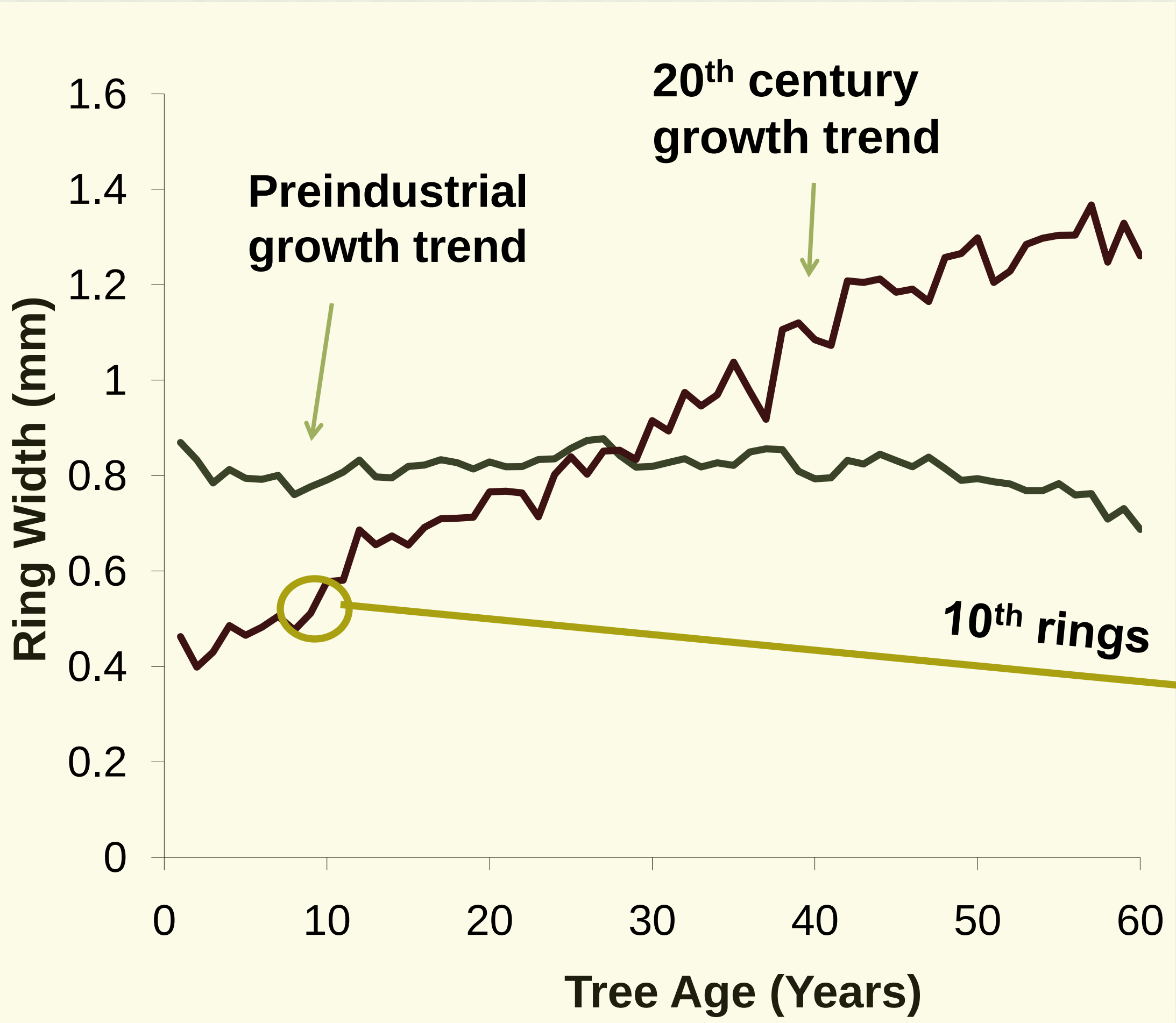
*Pinus edulis* (piñon pine) is a foundation species in the piñon-juniper woodlands of the Southwest covering 35% of the Colorado Plateau. Piñon pine mortality in the recent drought has been high<sup>1</sup>; climate change models predict additional water stress in the future<sup>2</sup>. In order to predict the fate of piñon pine, we must understand how various climatic factors influence piñon growth and how they interact with rising [CO<sub>2</sub>]. To address these questions, we used tree rings from 78 piñon pine trees cored at Red Mountain in northern Arizona in 1998 and 361 piñon pine cored across Arizona in the last 50 years. As a prelude to a full climate-based model, we analyzed growth in a given year based on growth in the preceding year and [CO<sub>2</sub>] in a hierarchical Bayes modeling structure. The model suggests strong inter-annual growth correlations and a positive effect of [CO<sub>2</sub>] on growth.



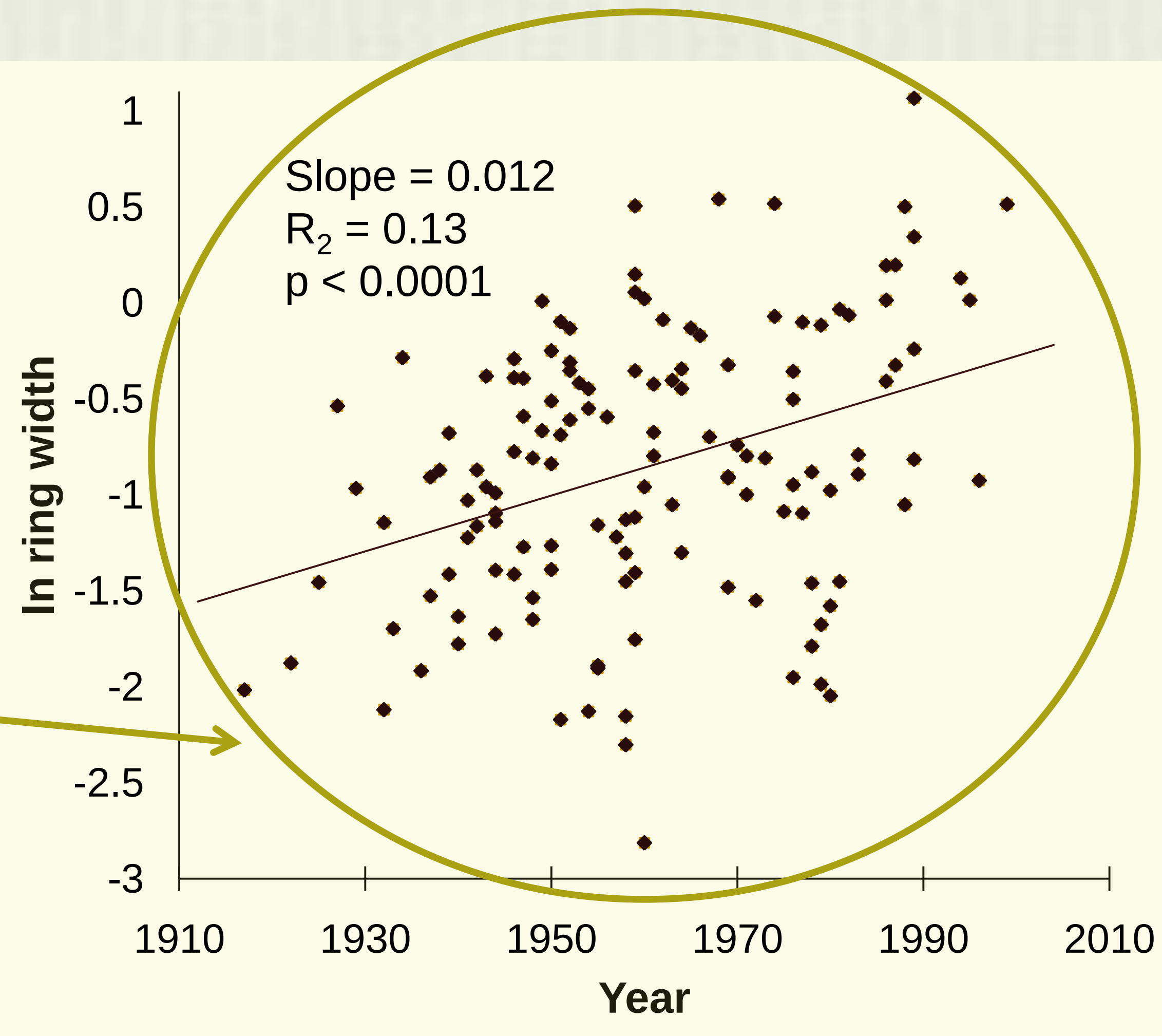
Piñon pine mortality at Red Mountain in Northern AZ

## Increasing ring widths are associated with elevated [CO<sub>2</sub>]

Piñon pine are growing faster as they age.



Piñon pine are growing faster over time.



We compared the radial growth as trees aged of piñon pine from sites across Arizona that began growing before large [CO<sub>2</sub>] increases (green line) with trees that began growing after large [CO<sub>2</sub>] increases (red line). Trees growing after [CO<sub>2</sub>] began increasing (after 1900) have an increasing radial growth trend. Trees growing before [CO<sub>2</sub>] began increasing (1380s through the 1700s) have a flat or slightly negative radial growth trend.

The 10<sup>th</sup> year of growth for each tree that began growing post-[CO<sub>2</sub>] increase is plotted above. Ring width is on a log scale (original measurements in mm).

The increasing trend is not just due to age effects as trees are also growing more over time. Ring widths from trees at a given age have a positive trend as [CO<sub>2</sub>] rises.

## Model

Our model is an autoregressive model with a lag of one year for tree ring growth  $y$  in year  $t$ ,

The autocovariance is integrated into the error term  $\epsilon_t$ , where  $\rho$  is the **autocorrelation coefficient**:

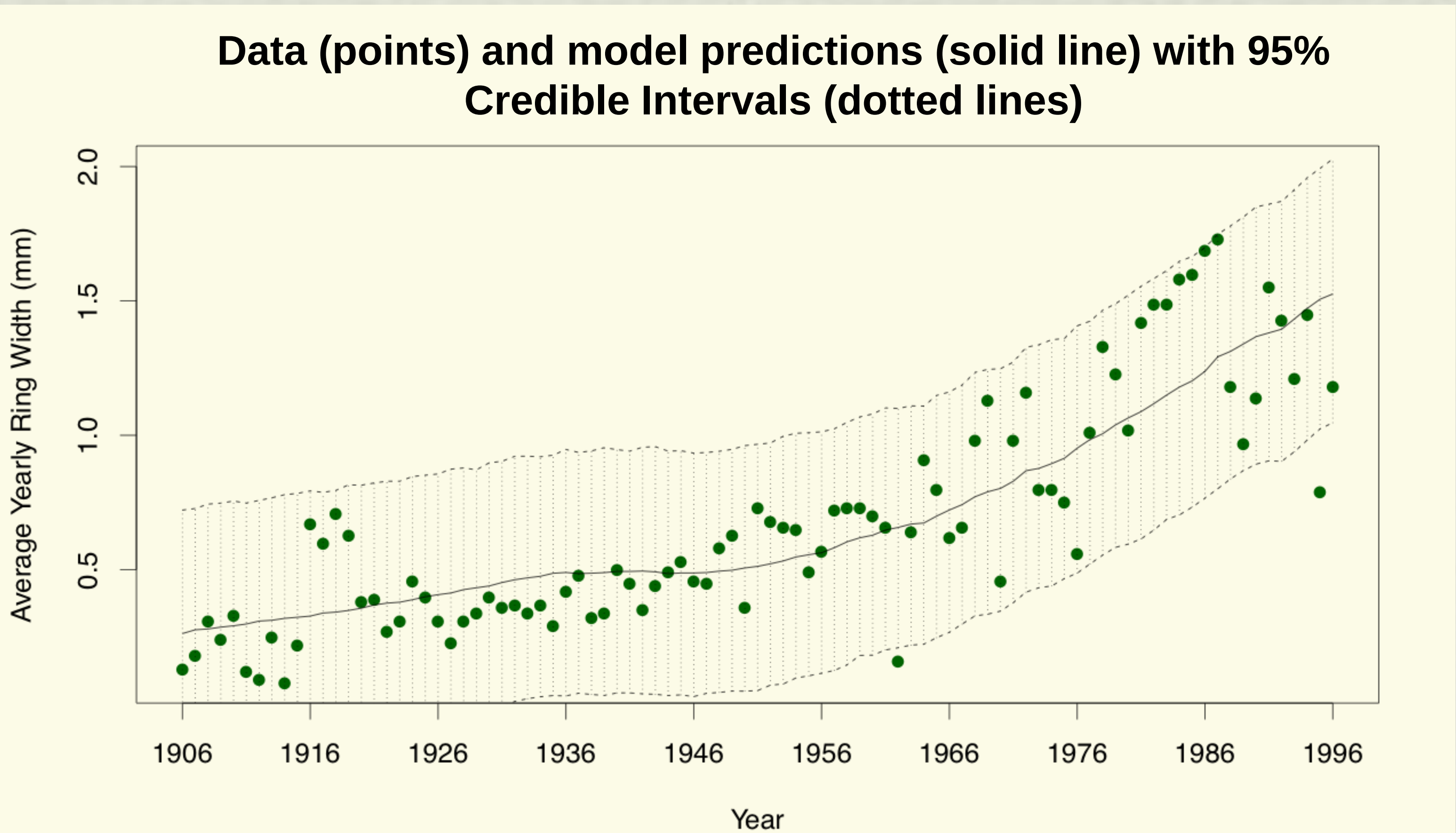
$$y_t = X\beta + \epsilon_t$$

$$\epsilon_t \sim N(\rho\epsilon_{t-1}, \sigma^2)$$

This year's growth =  
**Growth predicted by CO<sub>2</sub> + Error term**

We chose a Bayesian rather than a frequentist approach because of its versatility; other sources of data and prior information can be incorporated easily.

We used Markov-chain Monte Carlo to build posterior probability densities for each of the parameters in our model, including correlation strength and error variance, and used those densities to estimate parameter values.



## Results

**Increasing ring width is associated with higher [CO<sub>2</sub>]** with slope 0.019 (95% Credible Interval (CI) 0.015 to 0.024) and intercept -5.5 (95% CI -6.88 to -4.07).

**Growth in a given year has a strong effect on growth in the subsequent year** with an autocorrelation coefficient of 0.49 (95% CI 0.30 to 0.68).

The model successfully describes yearly average ring width, though ring width is overestimated in extremely dry years and the 95% credible interval includes negative ring widths.

## Conclusions

**Elevated [CO<sub>2</sub>] is likely responsible for recent piñon pine growth increases.**

Based on the difference in pre- and post-rising [CO<sub>2</sub>] ring width data, we believe autocorrelation is not as large as this model suggests. The autocorrelation estimate is so high in this model only because autocorrelation and [CO<sub>2</sub>] compete to explain the same trend in the data.

While other influences such as moisture and temperature are undoubtedly important to understanding piñon pine growth and mortality, [CO<sub>2</sub>] may be particularly important as the Southwest warms. As recent experiments indicate that piñon pine mortality can arise from drought-induced carbon starvation<sup>3</sup>, the contribution of increasing [CO<sub>2</sub>] to growth and improved water use efficiency could be very important to predicting piñon pine survival and migration.

## References

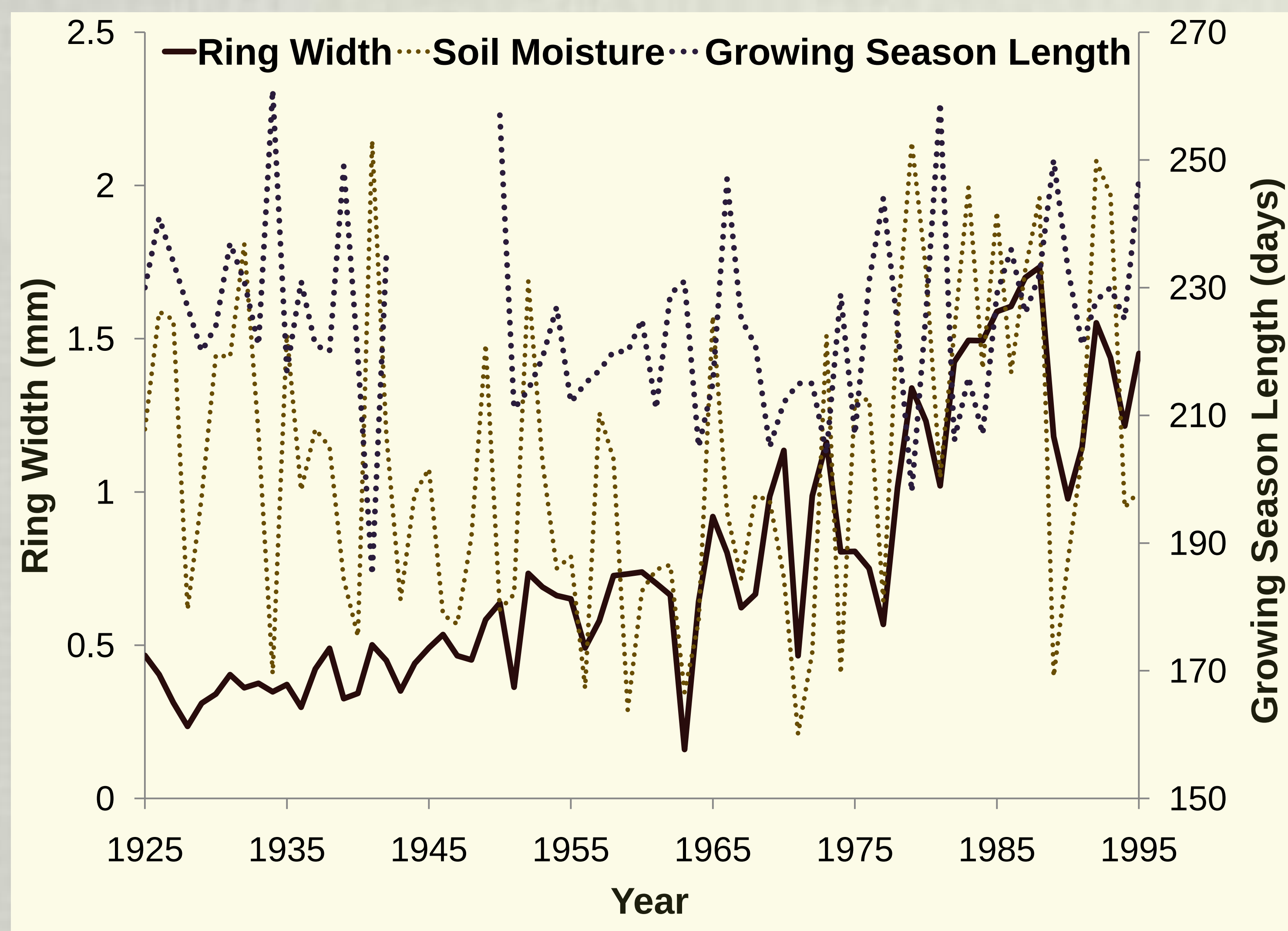
- 1 Breshears *et al.* Regional vegetation die-off in response to global-change-type drought. Proceedings of the National Academy of Sciences (2005)
- 2 Seager *et al.* Model Projections of an Imminent Transition to a More Arid Climate in Southwestern North America. Science (2007) vol. 316 (5828) pp. 1181-1184.
- 3 Adams *et al.* Temperature sensitivity of drought-induced tree mortality portends increased regional die-off under global change type drought. Proceedings of the National Academy of Sciences (2009)
- 4 Clark, J.S. Models for ecological data. Princeton University Press, Princeton, New Jersey, USA. (2007)

## Acknowledgements

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## Why are Piñon Pine Growing Faster?

Temperature, growing season, and moisture availability are frequently used to predict radial growth in trees. However, moisture levels (measured as the Palmer Drought Severity Index) and growing season length fail to explain recent increases in radial growth since neither have displayed consistent trends over this time period.



Elevated temperatures are also unable to account for recent increases in radial growth as piñon pine are growing more in both drought and wet years. Warmer temperatures could increase growth in normal and wet years, but in drought years they lead to increased mortality<sup>3</sup>.

Unlike these commonly used predictors, [CO<sub>2</sub>] has increased steadily over the same time period.