

Devising an ageing technique for *Artemisia tridentata* ssp. *vaseyana* near Crested Butte,  
Colorado

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NSF Research Experience for Undergraduates Program 2007  
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## Abstract

Due to climatic changes, sagebrush (*Artemisia tridentata* ssp. *vaseyana*) is likely to increase its elevational range in the Rocky Mountains, which could have significant effect on alpine communities. Little is known about the demographics of sagebrush populations, partially due to difficulties in ageing plants. This study examines the relationship between age and various physical attributes of sagebrush at four sites along an elevational gradient near Crested Butte, Colorado. We found the best correlations between age and diameter, although it is unclear how well these could be used to age sagebrush in the field. There was very little variation in ages across the sites, with most sites having plants as old as 45-55 years. However, the second lowest site was significantly younger than the rest of the sites, with the oldest plant only 33 years old. This is most likely due to heavy grazing at this site that is not present at any of the other sites. A general trend of increased ring widths at lower elevations was also noticed.

## Introduction

Mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*) is a perennial shrub that can be found in many semiarid regions of the western U.S. from low scrubland to subalpine (US Forest Service, 1937). Increased carbon dioxide levels have the potential to increase global temperatures by up to 6.4°C by the 21<sup>st</sup> century (IPCC, 2007). This warming could cause a reduction in soil moisture as well as an advance in the timing of snowmelt within the Rocky Mountains (Harte *et al.* 1995). Partially because of the earlier snowmelt, the effects of climate change are expected to be greatest at higher elevations due to longer growing periods along with warmer and drier summers (Harte and Shaw, 1995; Perfors *et al.*, 2003). Taken with increasing temperatures and aridity, especially in upper elevations, sagebrush populations have the potential to extend their range upwards into subalpine meadows.

An increase in sagebrush could have significant effects within montane and subalpine communities by decreasing diversity of local herbaceous species. Sagebrush could also cause feedbacks to climate change through changes in albedo or carbon storage. Saleska *et al.* (1999) showed that in artificially warmed plots there was a trend for a net carbon loss which would in

turn be a positive feedback on climate change. Unfortunately, little is known about how sagebrush will respond to a warmer, drier climate over multiple generations.

Sagebrush is very susceptible to low soil oxygen levels, and is unable to survive in poorly-drained soils (Lunt *et al.*, 1973). Sturges (1989) showed that if snowpack is too thick (more than about 2.8 m) and the soils are wet for too long in the spring the sagebrush population can be eliminated. Increased snowpack has been shown to have a similar effect on germination, potentially due to a snowmould that is active once temperatures rise over 0°C (Meyer and Monsen, 1991). Indeed, localized warming experiments near Crested Butte, Colorado have shown an increase in the growth rate of sagebrush as well as an increase in the rate of photosynthetic CO<sub>2</sub> uptake and efficiency of water use within warmed plots relative to control plots (Perfors *et al.*, 2003; Loik *et al.*, 2000).

A better understanding of age structures of sagebrush populations could tell us much about how climate change may affect sagebrush populations . By examining anomalies and fluctuations within the age structure it is possible to learn more about conditions for germination within those populations. Age-structures may also provide information about whether some of the sagebrush populations are recent invasions into subalpine meadows, as well as more information on the population dynamics.

A limited amount is known about the demographics of sagebrush in the Crested Butte area. In the northern Colorado Rocky Mountains, Roughton (1972) found cohorts within the age structure of a sagebrush population. Cawker (1980) found similar cohorts within populations in British Columbia and was able to show correlations with local climate data going back to 1922, and suggested that those cohorts represent climatic conditions favorable for sagebrush germination.

In order to conduct similar studies in the Crested Butte area, it is necessary to have a reliable method of aging the local populations of sagebrush. Sagebrush form annual rings which have been used both to age individual plants and to create age-stem diameter relationships (Perfors *et al.*, 2003; Roughton, 1972; Perryman and Olson, 2000). Unfortunately, these relationships have only been found to apply within local regions (Lab of Tree Ring Research Website). As Crested Butte is near the altitudinal limit of sagebrush there may be an even greater difference in correlations, so relationships developed elsewhere are probably not applicable for this area.

This study aims to determine correlations between age and physical attributes of sagebrush that are reliably measurable in the field. As the study sites are across an elevation gradient we also examined trends in ring width and age as they varied across the sites.

## **Methods**

Our study included four sites that range in elevation from approximately 2,500 m to 3,300 m along the East River drainage north of Gunnison, Colorado (Figure 1). The lowest site (2,500m) is near Almont, in low hills that are covered in sage and junipers. The next lowest site (2,800m), is located just outside of Mt. Crested Butte and is in a heavily grazed area. The third site (2,900m) is in the Research Meadow at the Rocky Mountain Biological Laboratories (RMBL) in Gothic and is within an alpine meadow within the original townsite. The highest site (3,300m) is on the side of Red Rock, a peak just southwest of RMBL, on a hill covered with dwarfed sagebrush. At each site we collected ten to fifteen plants for a total of 52 plants. One of the smallest and largest plants was collected at each site, with the others non-randomly selected to best cover all circumferences in-between.

For each plant sampled we collected field data on various physical attributes including circumference and diameter of the main stem, canopy dimensions, and the number of flowering stalks (Appendix 1). Circumference was measured using a measuring tape wrapped around the lowest portion of the main stem visible. The diameter was measured at the same spot using calipers. As sagebrush stems are rarely round, circumference and diameter were measured at the widest point. If the main stem was buried, we recorded the number of main branches visible and data were taken for the largest. We then collected the entire plant, digging up the main roots, and took GPS data points for each plant using GeoXT.

In the lab cross-sections were cut from the base of each plant and sanded so individual growth rings were clearly visible. We counted the rings using a dissecting scope and wetted the cross-sections to increase contrast. All plants where the center ring could not be found were excluded from the data (13 plants total, with 6 from the highest site). Aspect data could not be accurately calculated from GIS because of minute variations in local aspect, so it is excluded from this study.

### *Statistics*

Within each site the ages were plotted against the various field measurements (diameter, dimensions of the plant, number of main branches, diameter of the largest branch, number of flowering stalks) to find the best parameter for estimating age. Diameter alone appeared to have the closest correlation with age so Excel was used to calculate power regressions between the age and diameter of each cross-section within sites. We noticed differences between the diameters measured in the lab and those measured in the field (Figure 2) so the regressions were also run between age and the field data for diameter. These differences are most likely due to variations in diameter along the main stem. Because one plant collected at the Research

Meadow actually turned out to be two plants (RM3N and RM3S), that field data was invalid and the plants were excluded from the regression using field data.

In order to allow these regressions to be applicable to data collected in the field it was necessary to come up with a regression for plants where data could not be collected on the main stem. The main stem of sagebrush can often be difficult to measure accurately. Sometimes this is due to the stem being below the surface, but other times it is because the main stem is too deteriorated to allow accurate measurement. A power regression was used to correlate the age of the plant with the diameter of the largest branch. Unfortunately, field data was not available for this analysis, so only data collected in the lab could be used.

To look at differences between sites more closely, the average ring widths were calculated by dividing the radius by the number of rings and then analyzed across sites using a one-way analysis of variance (ANOVA) and a Tukey pairwise comparison. As one of the largest and smallest plants had been sampled at each site, it was assumed that the age range for that site had been captured, so the same analysis was run on the ages.

## **Results**

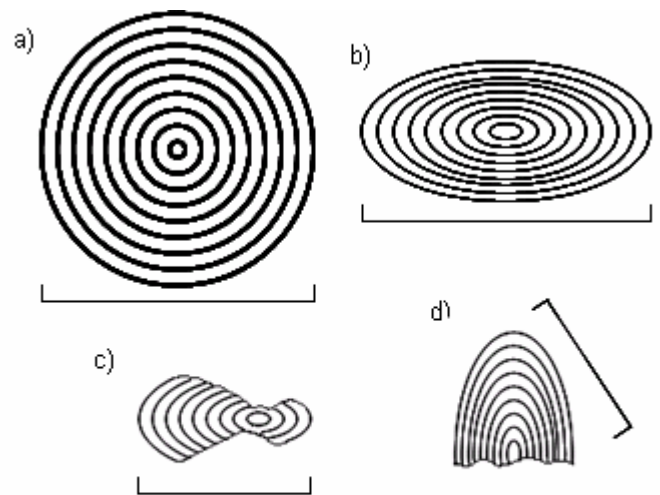
Neither the dimensions of the plant nor the number of branches were significantly affected by the age of the plant. However, there was a significant relationship between age and diameter with a lot of the variation in diameter explained by the age of the plant. This was true at all sites with  $R^2$  values ranging from 0.80-0.95 for the lab data (Figure 3). The diameters measured in the field did not explain the variations in age as closely, though they still explained most of the variation with  $R^2$  values between 0.73 and 0.96 (Figure 4). The diameter of the largest branch also explained a lot of the variation in ages with  $R^2$  values between 0.80 and 0.92 (Figure 5).

The ring widths were significantly different across sites (Figure 6, ANOVA:  $F_{3,35}=4.296$ ,  $P=0.003$ ) with Mt. Crested Butte having significantly larger rings than Red Rock (Tukey,  $P=0.023$ ). The ages of the plants sampled also differed across sites (Figure 7, ANOVA:  $F_{3,35}=4.456$   $P=0.009$ ). The Mt. Crested Butte site was significantly younger than the Almont site (Tukey,  $P=0.013$ ). Mt. Crested Butte was not significantly different from the Gothic and Red Rock sites (Tukey,  $P=0.058$  and  $P=0.068$  respectively) though this could be due to the small sample sizes.

## Discussion

The power regressions that were calculated using both the lab and field data were generally able to accurately predict the age of a plant, based only on the diameter of the plant. There are many reasons for why the diameter does not explain more of the variations in age (Figure 8). One of the main reasons is that sagebrush does not always grow in circles and is often elliptically shaped. Sometimes only a small arc is added on each year, often representing less than half of the actual circumference. Also, parts of the main stem can deteriorate while the plant is still alive. This means that when diameter is measured is often captures only part of what is normally conceived as the diameter of a cross-section.

The diameter of the largest branch also explained a lot of the variation in age, with the regression fitting the data well. As the branches of sagebrush are often less convoluted than the



**Figure 8:** The various growth habits for sagebrush rings. The largest diameter is indicated. a) spherical concentric rings b) elliptical concentric rings c) rings only in some directions d) Part rotted away, the center ring still visible

main stem, it is possible that there would be fewer differences between the lab and field data. Unfortunately, field measurements were not collected, so that hypothesis cannot be tested. If that was the case, it could be possible to use those data alone in calculating ages of sagebrush in order to avoid the potential inaccuracies and physical difficulties inherent in taking data on the main stem of the plant.

It was also observed that the ring widths varied with elevation, with a general trend of the higher sites having smaller rings. This is probably due to the shorter growing season at higher elevation because of later snowmelts in the spring and earlier first freezes in the fall. The only exception was the Mt. Crested Butte site which actually appeared to have larger rings than Almont, although this was not significant. One reason for this could be a variation in aspect, as the Mt. Crested Butte site is slightly more north facing which could have a slightly wetter, cooler environment. However, as studies have shown increased growth on warmer, drier plots, this probably is not a major contributing factor (Perfors *et al.*, 2003). Another factor could be the variations in age. Mt. Crested Butte was significantly younger than two of the other sites, and appeared to be younger than the third, although not significantly. As plants often have higher growth rates at younger ages, this could be contributing to the observed variation in ring widths. This implies that while the general trend might be for smaller rings at higher elevation, both age and aspect may also play a role.

This study has shown that it is possible to devise an ageing technique for sagebrush near Crested Butte, Colorado. While this model can be based on the diameter of the main stem, a model created using the diameter of the main branch could be more accurate due to issues with accurately measuring the diameter of the main stem. More study needs to be conducted, especially with field data for the diameter of the main branch to see how well it matches the lab

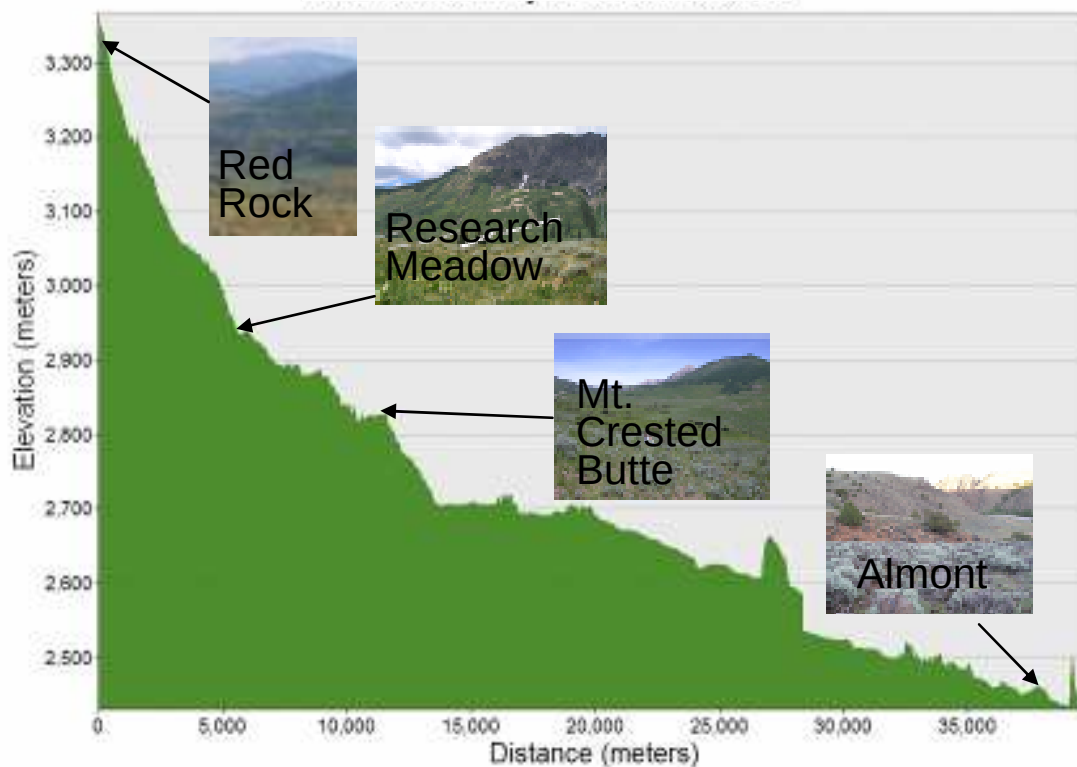
data. Also, data should be collected and examined to see what role, if any, aspect could have in increasing the accuracy of predictions. These models should be applied to local populations of sagebrush to create age structures so that more can be learned about their population dynamics.

### **Acknowledgements**

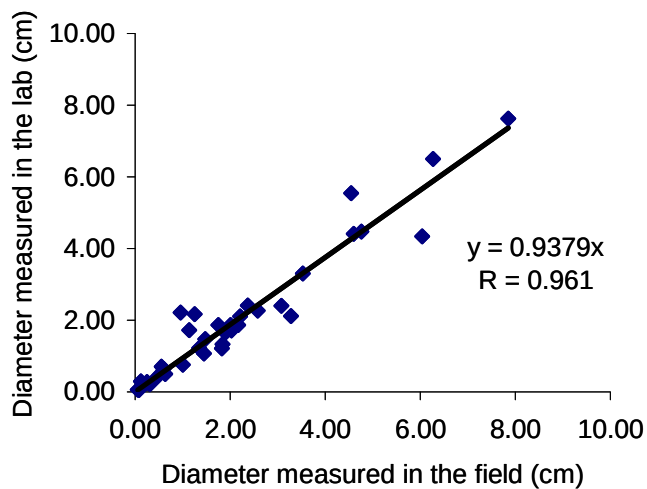
This project was funded by the National Science Foundation Research Experience for Undergraduates program and could not have been done without the support of The Rocky Mountain Biological Laboratories. Brian Enquist and Christine Lamanna were instrumental for their help directing this project and offering insight along the way. Robin Sleith helped immensely with collecting and processing sagebrush, and many people at RMBL offered their invaluable opinions; specifically Jennifer Reithel , Laura Aldrich-Wolfe and John Harte.

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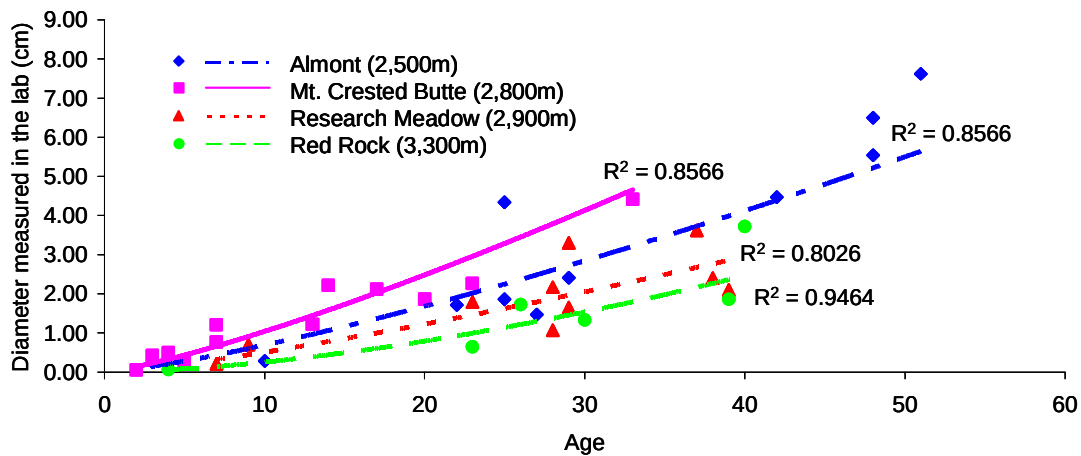
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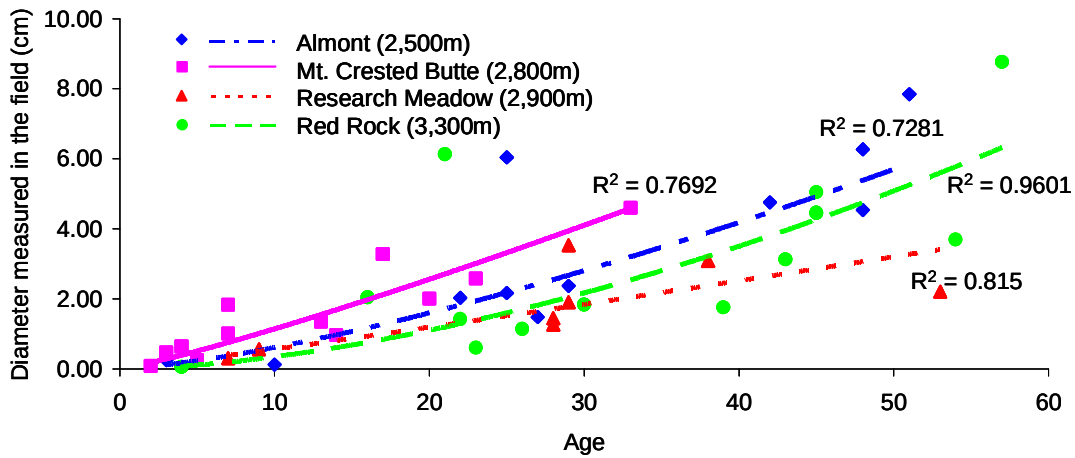
**Figure 1:** The four sites: Almont (2,500m), Mt. Crested Butte (2,800m), Research Meadow (2,900m) and Red Rock (3,300m). Elevation diagram courtesy of Robin Sleith.



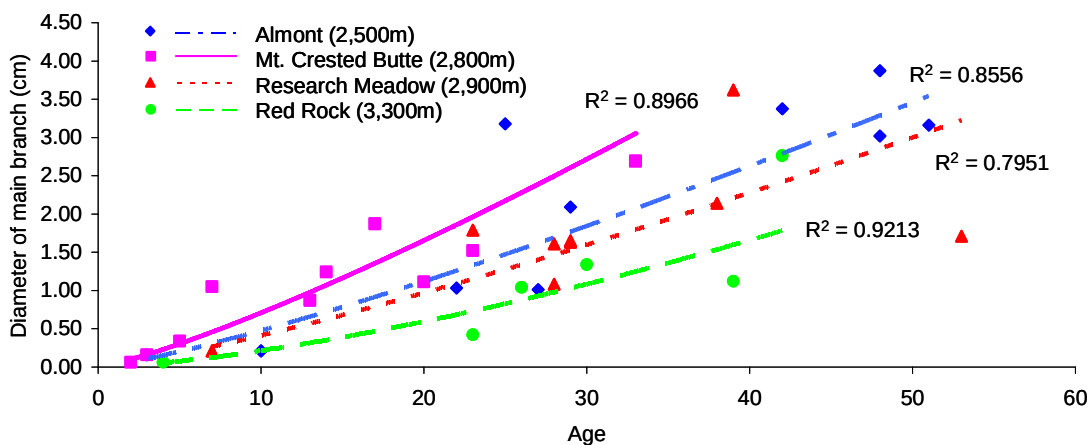
**Figure 2:** Demonstrates the differences between diameters measured in the field and diameters measured in the lab.



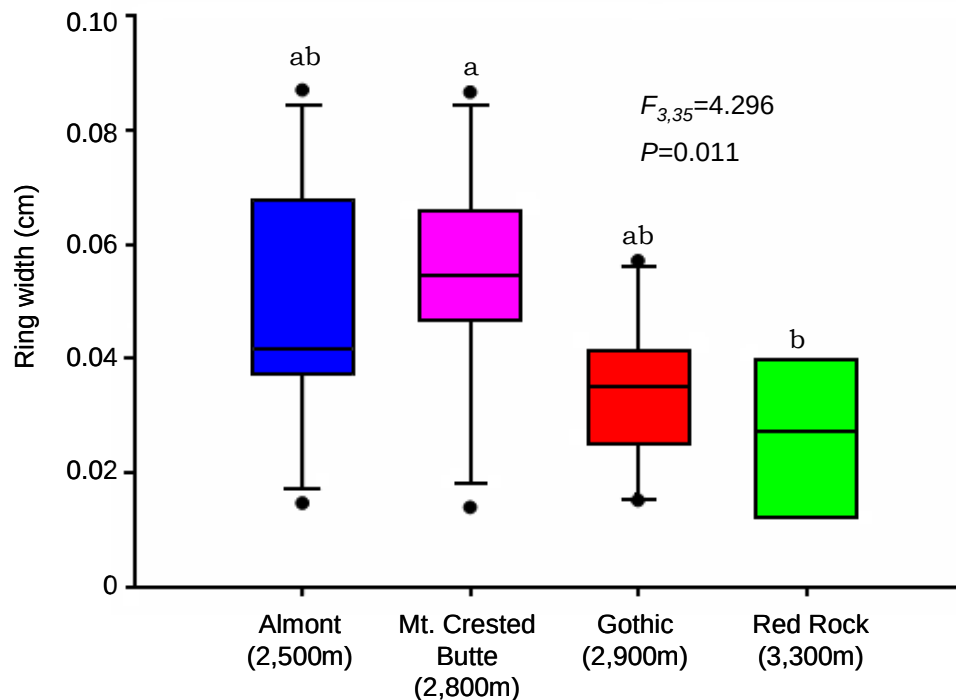
**Figure 3:** Data and power regressions for the correlation between age and the diameter measured in the lab. The R-squared values are associated with the line they are closest to.



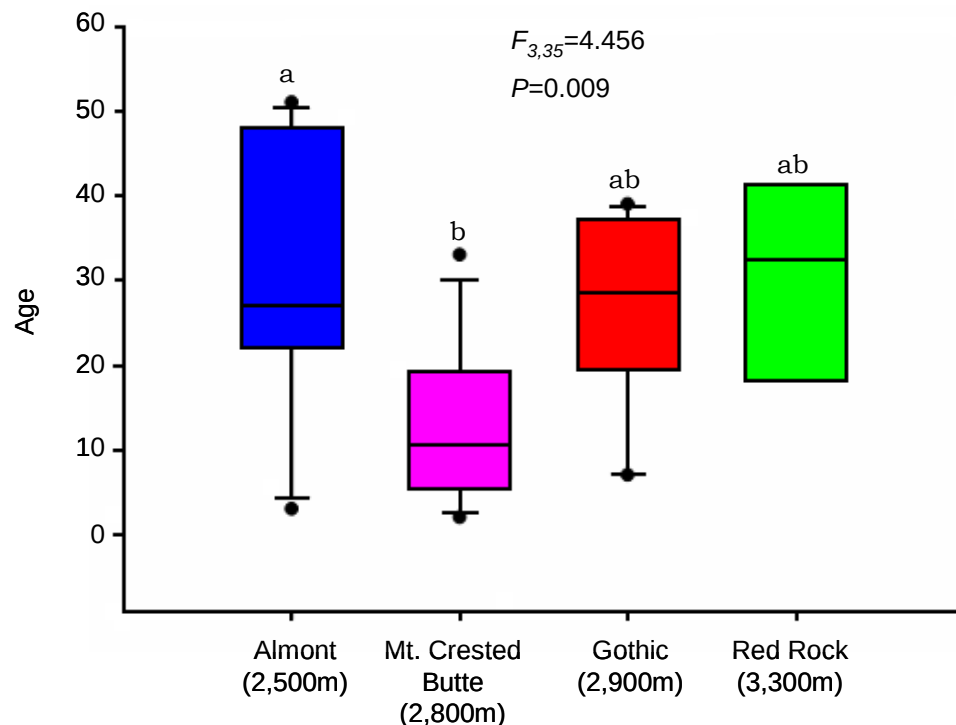
**Figure 4:** Data and power regressions for the correlation between age and the diameter measured in the field. The R-squared values are associated with the line they are closest to.



**Figure 5:** Data and power regressions for the correlation between age and the diameter of the main branch (measured in the lab). The R-squared values are associated with the line they are closest to.



**Figure 6:** Variation in ring width both within and across the sites. The middle line is the mean, and the error bars are the 90% confidence intervals. There are no error bars for Red Rock, as the sample size is too small ( $n=6$ ). The P-value is from a one way analysis of variance and the letters indicate the results of a Tukey pairwise comparison.



**Figure 7:** Variation in ages both within and across the sites. The middle line is the mean, and the error bars are the 90% confidence intervals. There are no error bars for Red Rock, as the sample size is too small ( $n=6$ ). The P-value is from a one way analysis of variance and the letters indicate the results of a Tukey pairwise comparison.

**Appendix 1:** Data collected for each plant, and the main cross-section. All plants where the center ring could not be found were excluded from the data (shaded cells). One plant collected at the Research Meadow turned out to be two plants (RM3N and RM3S) so that field data was invalid. The diameters for Red Rock were not all collected due to an incoming thunderstorm.

| Site              | Elevation (m) | Plant | Field Measurements: |               |             |             |             |         | X-section: |           |         |                 |                  |
|-------------------|---------------|-------|---------------------|---------------|-------------|-------------|-------------|---------|------------|-----------|---------|-----------------|------------------|
|                   |               |       | Circumference (cm)  | Diameter (cm) | Height (cm) | Width1 (cm) | Width2 (cm) | # Stems | Circ (cm)  | Diam (cm) | # Rings | Center Visible? | Greatest # rings |
| Almont            | 2462          | AL1   | 26.2                | 8.77          | 42          | 41          | 38          | 1       | 22.7       | 8.30      | 49      | no              | 57               |
| Almont            | 2462          | AL2   | 7.4                 | 2.03          | 19          | 26          | 20          | 1       | 6.0        | 1.71      | 22      | yes             | 22               |
| Almont            | 2462          | AL3   | 20.1                | 6.27          | 45          | 89          | 66          | 1       | 19.0       | 6.50      | 48      | yes             | 48               |
| Almont            | 2462          | AL4   | 16.4                | 5.05          | 28          | 45          | 40          | 1       | 13.9       | 4.22      | 45      | no              | 45               |
| Almont            | 2462          | AL5   | 13.6                | 4.76          | 34          | 52          | 42          | 1       | 12.9       | 4.47      | 42      | yes             | 42               |
| Almont            | 2462          | AL6   | 4.8                 | 1.48          | 21          | 14          | 11          | 1       | 4.2        | 1.47      | 27      | yes             | 27               |
| Almont            | 2462          | AL7   | 9.3                 | 3.13          | 38          | 20          | 13          | 1       | 9.5        | 3.08      | 34      | no              | 43               |
| Almont            | 2462          | AL8   | 22.5                | 7.85          | 82          | 125         | 90          | 1       | 21.6       | 7.62      | 51      | yes             | 51               |
| Almont            | 2462          | AL9   | 15.5                | 4.54          | 42          | 66          | 47          | 1       | 14.9       | 5.54      | 48      | yes             | 48               |
| Almont            | 2462          | AL10  | 0.9                 | 0.25          | 10          | 6           | 5           | 1       | 1.1        | 0.25      | 3       | yes             | 3                |
| Almont            | 2462          | AL11  | 0.4                 | 0.12          | 2           | 3           | 2           | 1       | 1.1        | 0.29      | 10      | yes             | 10               |
| Almont            | 2462          | AL12  | 8.2                 | 2.37          | 24          | 36          | 29          | 1       | 8.0        | 2.41      | 29      | yes             | 29               |
| Almont            | 2462          | AL13  | 12.1                | 3.70          | 46          | 26          | 23          | 1       | 11.4       | 3.84      | 54      | no              | 54               |
| Almont            | 2462          | AL14  | 16.5                | 6.04          | 46          | 62          | 61          | 1       | 12.2       | 4.34      | 25      | yes             | 25               |
| Almont            | 2462          | AL15  | 7.2                 | 2.17          | 18          | 35          | 22          | 1       | 6.1        | 1.86      | 25      | yes             | 25               |
| Mt. Crested Butte | 2808          | RO1   | 6.2                 | 2.01          | 35          | 43          | 39          | 1       | 6.2        | 1.86      | 20      | yes             | 20               |
| Mt. Crested Butte | 2808          | RO2   | 19.3                | 6.13          | 49          | 108         | 68          | 1       | 6.4        | 2.31      | 20      | no              | 21               |
| Mt. Crested Butte | 2808          | RO3   | 9.8                 | 3.28          | 30          | 74          | 44          | 1       | 7.2        | 2.11      | 17      | yes             | 17               |
| Mt. Crested Butte | 2808          | RO4   | 4.0                 | 0.96          | 32          | 47          | 30          | 1       | 7.1        | 2.21      | 14      | yes             | 14               |
| Mt. Crested Butte | 2808          | RO5   | 5.1                 | 1.83          | 24          | 47          | 27          | 1       | 4.5        | 1.21      | 7       | yes             | 7                |
| Mt. Crested Butte | 2808          | RO6   | 0.3                 | 0.08          | 4           | 1           | 1           | 1       | 0.2        | 0.06      | 2       | yes             | 2                |
| Mt. Crested Butte | 2808          | RO7   | 14.5                | 4.60          | 36          | 89          | 44          | 1       | 13.8       | 4.41      | 33      | yes             | 33               |
| Mt. Crested Butte | 2808          | RO8   | 5.2                 | 1.42          | 26          | 27          | 19          | 1       | 5.7        | 1.65      | 15      | no              | 22               |
| Mt. Crested Butte | 2808          | RO9   | 2.1                 | 0.47          | 10          | 15          | 14          | 1       | 1.8        | 0.42      | 3       | yes             | 3                |
| Mt. Crested Butte | 2808          | RO10  | 4.9                 | 1.35          | 27          | 31          | 25          | 1       | 4.6        | 1.22      | 13      | yes             | 13               |
| Mt. Crested Butte | 2808          | RO11  | 1.2                 | 0.25          | 21          | 11          | 4           | 2       | 1.1        | 0.28      | 5       | yes             | 5                |
| Mt. Crested Butte | 2808          | RO12  | 3.5                 | 1.01          | 26          | 17          | 16          | 1       | 2.8        | 0.76      | 7       | yes             | 7                |
| Mt. Crested Butte | 2808          | RO13  | 7.8                 | 2.58          | 37          | 65          | 54          | 2       | 7.0        | 2.26      | 23      | yes             | 23               |
| Mt. Crested Butte | 2808          | RO14  | 6.5                 | 2.05          | 23          | 49          | 15          | 1       | 7.2        | 2.66      | 8       | no              | 16               |
| Mt. Crested Butte | 2808          | RO15  | 2.7                 | 0.64          | 18          | 19          | 15          | 1       | 2.2        | 0.50      | 4       | yes             | 4                |
| Research Meadow   | 2926          | RM1   | 11.8                | 3.53          | 40          | 64          | 60          | 1       | 11.3       | 3.30      | 29      | yes             | 29               |
| Research Meadow   | 2926          | RM2   | 9.2                 | 3.08          | 35          | 61          | 53          | 1       | 7.2        | 2.40      | 38      | yes             | 38               |
| Research Meadow   | 2926          | RM3N  |                     |               |             |             |             |         | 5.1        | 1.79      | 23      | yes             | 23               |
| Research Meadow   | 2926          | RM3S  |                     |               |             |             |             |         | 11.4       | 3.62      | 37      | yes             | 39               |
| Research Meadow   | 2926          | RM4   | 6.4                 | 1.90          | 32          | 35          | 24          | 1       | 5.5        | 1.65      | 29      | yes             | 29               |
| Research Meadow   | 2926          | RM5   | 4.2                 | 1.26          | 36          | 12          | 5           | 1       | 7.2        | 2.17      | 28      | yes             | 28               |
| Research Meadow   | 2926          | RM6   | 3.0                 | 0.56          | 18          | 16          | 13          | 1       | 2.4        | 0.70      | 9       | yes             | 9                |
| Research Meadow   | 2926          | RM7   | 1.1                 | 0.31          | 12          | 3           | 2           | 1       | 0.9        | 0.21      | 7       | yes             | 7                |
| Research Meadow   | 2926          | RM8   | 4.9                 | 1.45          | 22          | 23          | 22          | 1       | 4.8        | 1.07      | 28      | yes             | 28               |
| Research Meadow   | 2926          | RM9   | 7.2                 | 2.21          | 38          | 35          | 20          | 1       | 6.7        | 2.10      | 39      | yes             | 53               |
| Red Rock          | 3305          | AT1   | 9.3                 |               | 36          | 51          | 40          | 3       | 12.2       | 4.04      | 42      | no              | 42               |
| Red Rock          | 3305          | AT2   | 19.8                |               | 30          | 89          | 87          | 1       | 13.6       | 4.73      |         | no              | 45               |
| Red Rock          | 3305          | AT3   | 2.4                 |               | 7           | 7           | 5           | 1       | 2.8        | 0.92      | 25      | no              | 31               |
| Red Rock          | 3305          | AT4   | 2.4                 |               | 7           | 20          | 7           | 1       | 2.1        | 0.64      | 23      | yes             | 23               |
| Red Rock          | 3305          | AT5   | 6.8                 |               | 30          | 38          | 35          | 1       | 7.1        | 2.16      | 26      | no              | 26               |
| Red Rock          | 3305          | AT6   | 6.2                 |               | 22          | 29          | 28          | 2       | 6.0        | 1.68      | 39      | yes             | 39               |
| Red Rock          | 3305          | AT7   | 4.9                 |               | 22          | 98          | 68          | ~10     | 11.0       | 3.72      | 40      | yes             | 42               |
| Red Rock          | 3305          | AT8   | 4.0                 | 1.14          | 32          | 49          | 41          | 3       | 5.7        | 1.72      | 26      | yes             | 26               |
| Red Rock          | 3305          | AT9   | 6.4                 | 1.84          | 24          | 34          | 21          | 1       | 4.1        | 1.33      | 30      | yes             | 30               |
| Red Rock          | 3305          | AT10  | 5.1                 |               | 25          | 32          | 30          | 1       | 9.6        | 2.77      | 23      | no              | 35               |
| Red Rock          | 3305          | AT11  | 8.8                 | 3.34          | 36          | 89          | 71          | 7       | 1.6        | 0.42      | 19      | no              | 19               |
| Red Rock          | 3305          | AT12  | 1.8                 |               | 10          | 3           | 3           | 1       | 0.2        | 0.06      | 4       | yes             | 4                |