

The effects of climate change on subalpine fir (*Abies lasiocarpa*) sapling growth and establishment success across an elevational gradient

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Research Experience for Undergraduates Program

Summer 2006

## Abstract

With the current climate changes occurring globally, it is important to learn about how species distributions will react in the future. Questions have arisen as to whether species, including conifers, exist in a single or multiple climate envelopes which are described by their current distributions. This study aims to investigate this question with subalpine fir (*Abies lasiocarpa*) as it occurs around Gothic, Gunnison Co., CO. Growth and establishment success were measured in 50 to 100 saplings in each of 11 populations across a climate gradient. Large variation was found among sites, suggesting that perhaps sites are reacting differentially to recent climate changes. It is not clear from this study whether subalpine fir trees are occupying a common climate envelope or if they are occurring in unique envelopes.

## Introduction

Climate changes that have occurred in the past 30 years are having increased effects on the distribution of many species whose ranges are temperature-limited, usually causing them to shift (Thomas *et al.* 2003). Competing hypotheses exist as to exactly how a species will react to climate shifts which are based on certain evolutionary assumptions. Questions also exist as to how species that exist along a climate gradient are being differentially selected for under varying climatic conditions. One hypothesis, brought forth by Harte, *et al.* (2004), is that a species may exist within a single climate envelope. In this situation the populations in the interior of the envelope are at their climatic optimum, and those on the edges are not. If this is the case, then we would expect sites at the warmer edge of the envelope to favor cooler climates, those at the cooler end to favor warmer climates, and those in the middle to not differentially favor either. Alternately, a species may exist within several climate envelopes, where each population has its own optimum climate. If this is present, then we would assume that all sites are currently at their climatic optimum, and that they would react negatively to any change in climate.

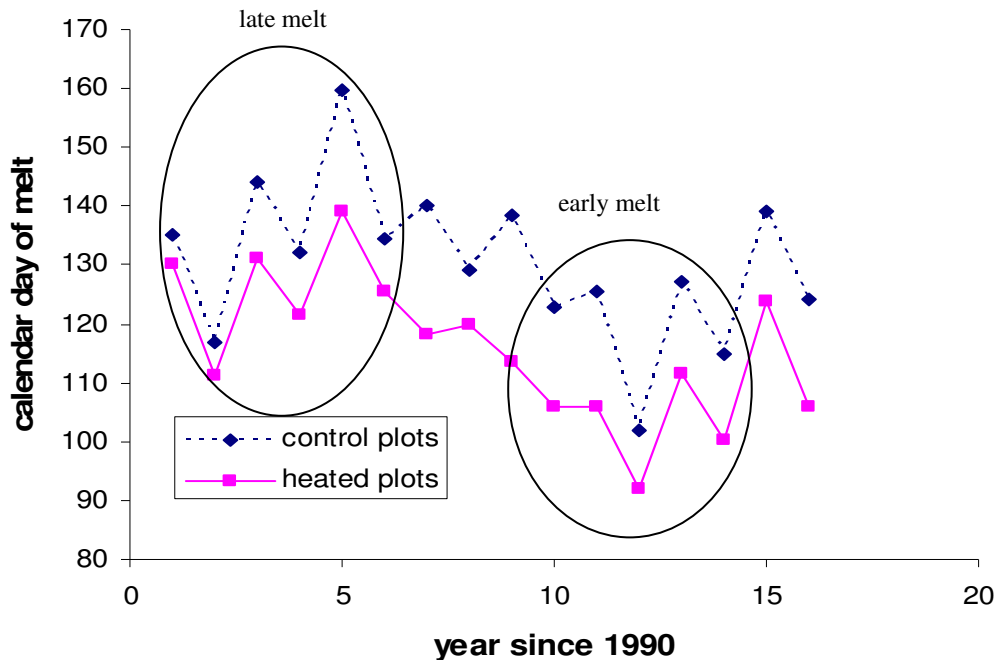
Climate change in alpine systems can be observed in the form of differential snowmelt date. While the actual date of snowmelt may differ with elevation and amount of snowfall, an earlier-than-average snowmelt date can usually be used as a reliable proxy for climate warming. Data from the warming meadows at the RMBL have recorded two significant periods of differential snowmelt dates: 1993-1997, which exhibited late snowmelt dates, and 2000-2004, where earlier-than-normal snowmelt dates were observed (Harte, unpublished data). Earlier snowmelt may be a result of global warming,

and thus its effect is valuable in analyzing how alpine plants will respond to this change in climate.

Subalpine fir (*Abies lasiocarpa*) exists at high elevations ranging from 2600 m to 3650 m, and often coexists with Engelmann's spruce (*Picea engelmannii*) (Harrington, 1954). It has been found that subalpine fir in the lower part of its elevational range (below 3050 m) responds negatively to earlier snowmelt than in normal years in the form of reduced growth and establishment success (Staaterman and Harte, 2004). Alternately, lodgepole pine (*Pinus contorta*) saplings, which live at lower elevations than subalpine fir, have been found to respond positively to earlier snowmelt dates (Perkins, 2005). One of the main questions this project will address is how the change in snowmelt date has affected the growth and establishment success of subalpine fir (*Abies lasiocarpa*) in populations at elevations greater than 2600 m. It is hypothesized that fir saplings that exist at the warmer end of their distribution will show depressed growth and establishment success during the years of earlier snowmelt than during the years of later snowmelt.

Certain environmental factors vary across elevational gradients which may affect the degree to which plants in the area are affected by earlier snowmelt dates. An additional objective of this study is to identify which environmental factors most heavily dictate the degree to which climate change affects subalpine fir sapling growth and establishment success.

## Warming Meadow Snowmelt Date



Adapted from Harte, 2006

### Methods

Conifer saplings were sampled because their establishment and survival will dictate the growth (or decline) of a population in changing climatic conditions. Additionally, young trees may be more sensitive to changes in the timing of snowmelt than mature trees, so any changes in growth due to climate change should be more visible in juveniles. Each year, juvenile conifers grow a new whorl of branches. The age of a given juvenile can be determined by simply counting the number of branch whorls beginning at the apical meristem of the plant. The internode length (the space between branch whorls) was used to estimate the amount of growth the plant exhibited in the year it was produced. The total age of each sapling was recorded, as well as the internode length for the most recent 13 years of growth.

This study included plants from 13 sites above 2750 m, including sites in Washington Gulch, Red Rock, and Virginia Basin. All 50 to 100 of the saplings found within a site were measured, thereby causing the area of each site to vary according to the relative density of saplings in the site. Several environmental traits were recorded at each site including elevation, aspect, slope, and canopy openness.

All statistical analyses were performed independently at each site. Two-tailed t-tests were used to statistically compare mean growth and establishment values in the wet and dry periods for each site, and for ages < 10 y. Growth in both periods compared by dividing the difference in growth between wet and dry years by the sum of them [(wet growth – dry growth) / (wet growth + dry growth)].

Certain environmental factors more heavily affect the degree to which subalpine fir saplings' growth are affected by differential snowmelt dates. This is important to the study, because sites with common environmental traits may show similar patterns in sapling reaction to climate change. Sites were assigned climate values, which were calculated by multiplying the elevation by the aspect (number of degrees from due south) and dividing it by 1000 (table 1).

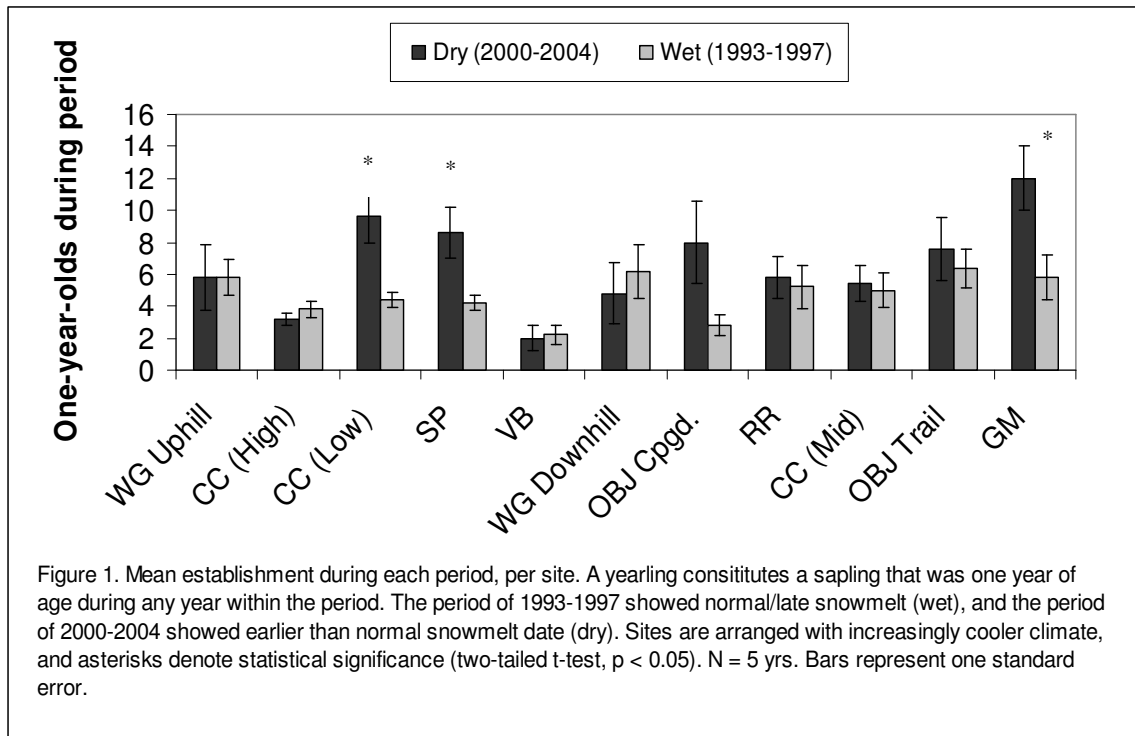
Table 1. Sites ranked according to their relative climate.

Climate value = (Aspect (from S) x Elevation)/1000

|          |                              | Degrees from S | Elevation<br>(m) | Climate<br>Value |
|----------|------------------------------|----------------|------------------|------------------|
| Warm/Dry | Washington Gulch Uphill      | 10             | 3375             | 34               |
|          | Copper Creek (High)          | 40             | 3303             | 132              |
|          | Copper Creek (Low)           | 90             | 3034             | 273              |
|          | Schofield Pass               | 84             | 3389             | 285              |
|          | Virginia Basin               | 90             | 3362             | 303              |
|          | Washington Gulch<br>Downhill | 95             | 3324             | 316              |
|          | OBJ Campground               | 145            | 2736             | 397              |
|          | Red Rock                     | 130            | 3219             | 418              |
|          | Copper Creek (Med)           | 140            | 3141             | 440              |
|          | OBJ Trail                    | 165            | 2846             | 470              |
|          | Cool/Wet                     |                |                  |                  |
|          | Gothic Mtn. 403 trail        | 178            | 3130             | 557              |

## Results

Sapling growth and establishment information were collected at 15 sites, and environmental data were collected at 11 of those sites. Three sites, Copper Creek (low elev.), Schofield Pass, and Gavin's Mountain, showed significantly greater establishment success during the more recent dry years, while the other sites showed a similar, yet less strong, trend (fig. 1). While Copper Creek (low elev.) and Schofield Pass showed similarly warmer climates, Gavin's Mountain exhibited one of the coolest climates, according to its climate value.

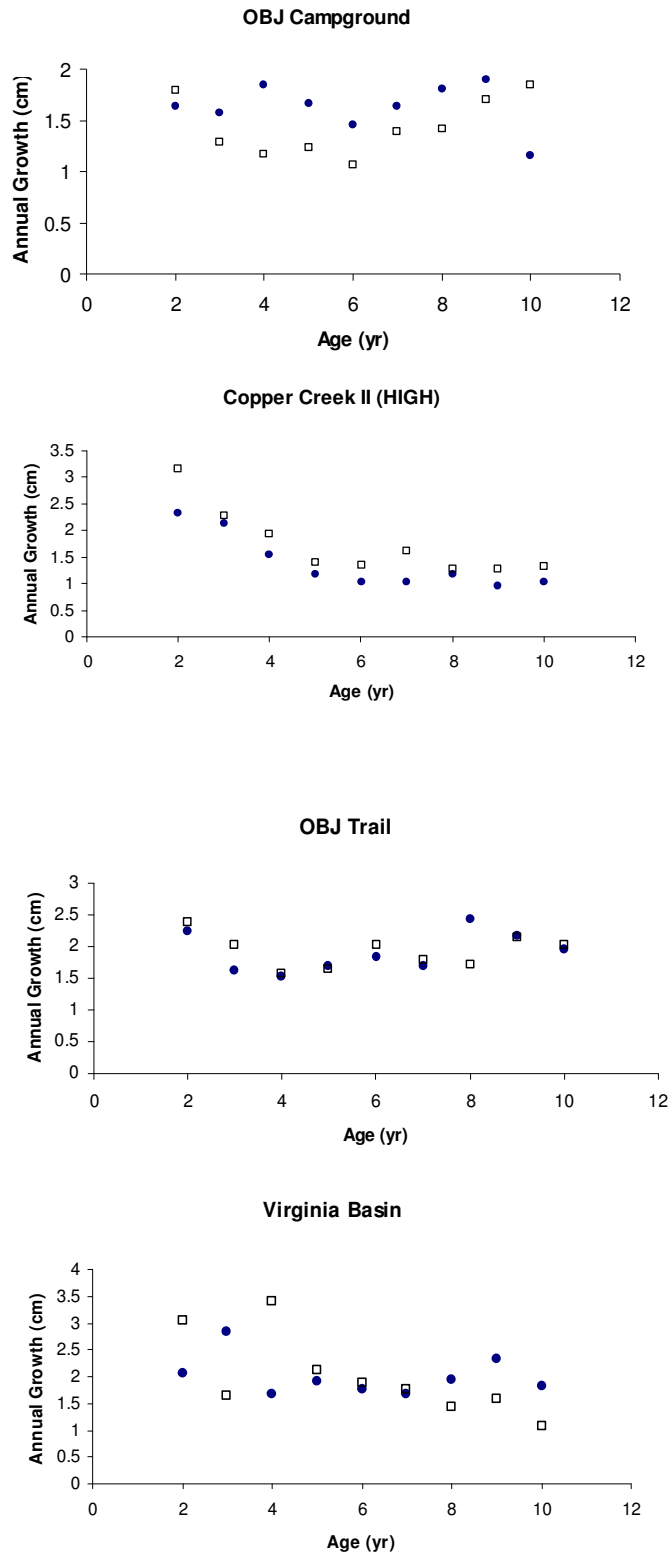


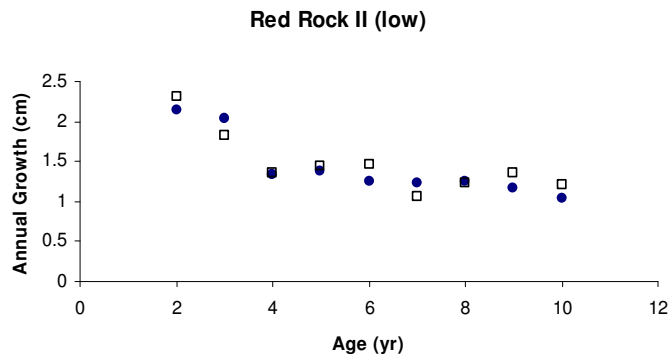
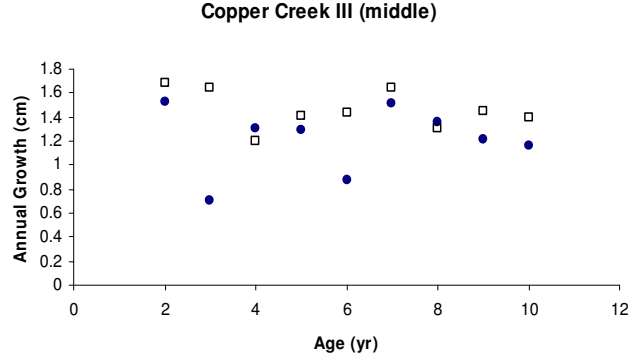
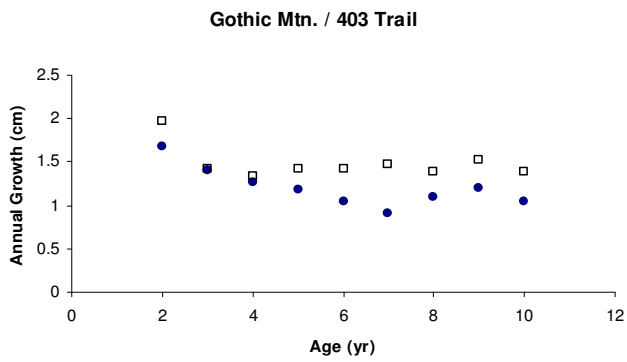
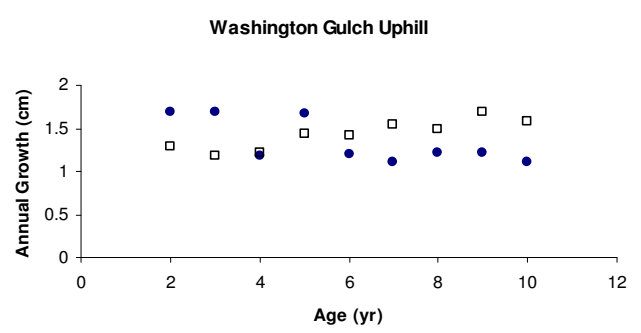
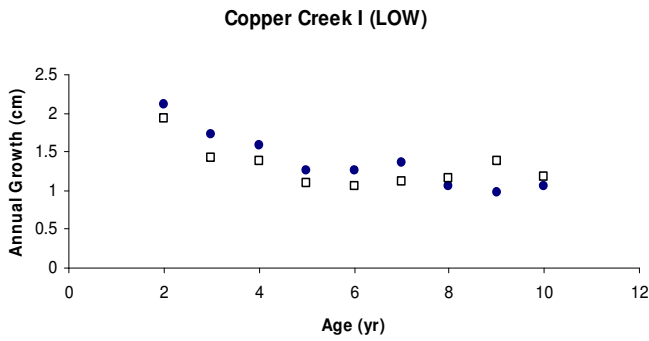
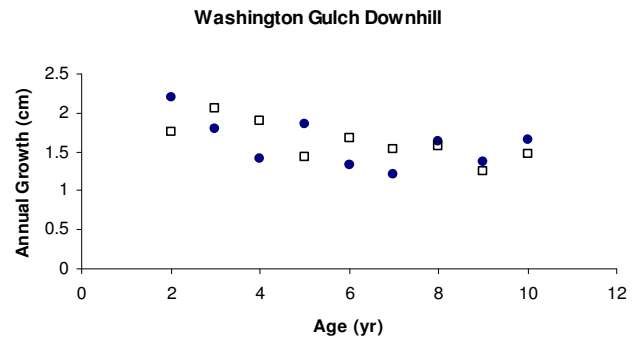
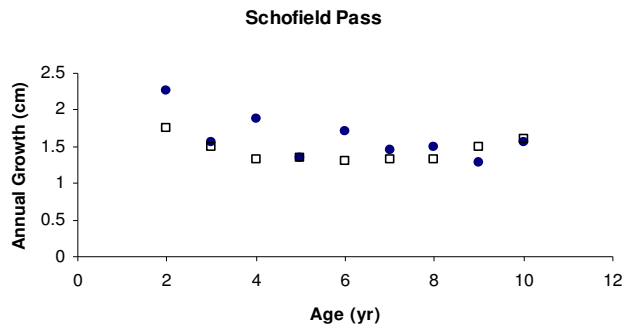
Analysis of all sites together shows no significant relationship between age and growth change (fig. 2), however individual sites seemed to show interesting growth patterns with age. There is a general trend that as age increases, annual growth (in cm) decreases, although the strength of this trend varies with site. Also, each site showed distinct patterns in favoring wet

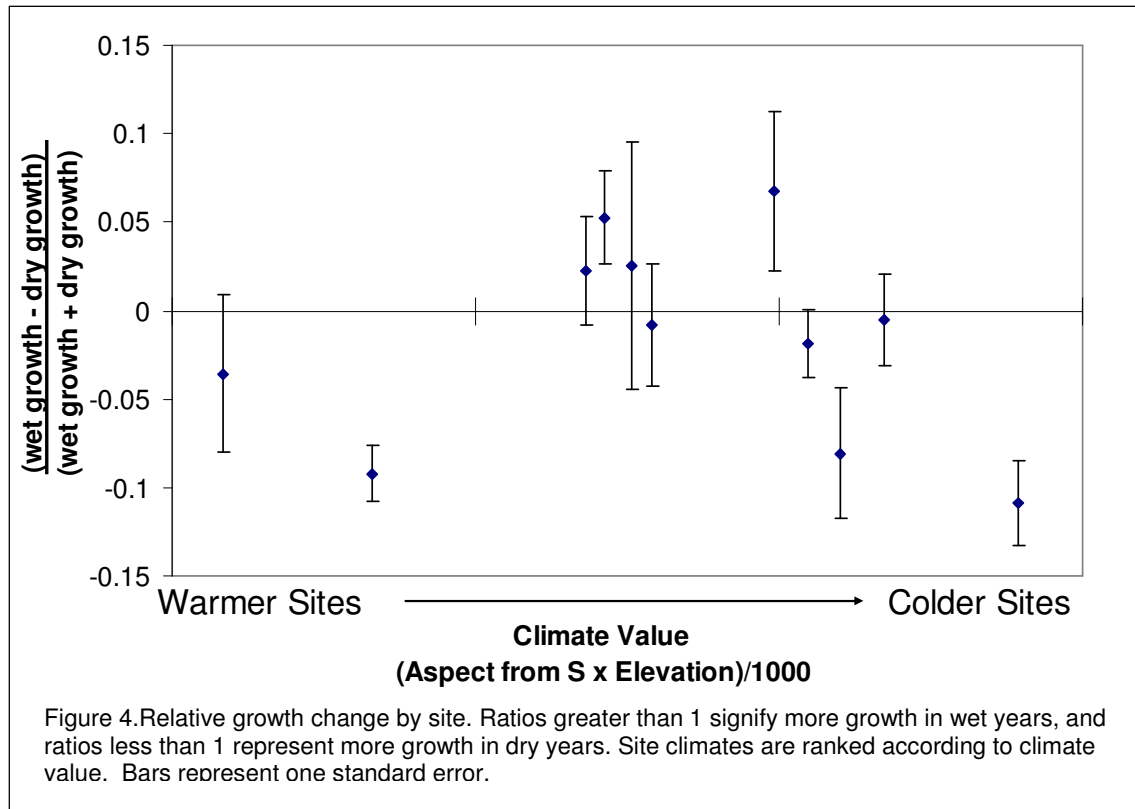
or dry years (fig. 3). Sites that showed extremely warmer or cooler climates showed preference to growth in the wet years, and sites with intermediate climate values showed more growth during the wet years (fig. 4).



Figure 3. Mean growth (cm) by age, at each site. Filled circles were grown in the wet period (1993-1997), open squares were grown in the dry period (2000-2004).







## Discussion

Conifer sapling growth rates change with age. This study has found that saplings younger than 10 years of age show slight tendencies toward preferring dry climate as they get older, although these patterns varied substantially by site. By taking into account the climate values assigned to each site and the trend of climatic preference each exhibited, some patterns are apparent. Two of the relatively cool sites, Gothic Mtn./403 Trail, Copper Creek III (middle elev.), showed more growth during the dry years, and two of the dry sites, Virginia Basin and Copper Creek I (low) showed more growth in the wet years. This supports the first hypothesis that there may be a single climate envelope, because the sites on the edges of the envelope are preferring climates that are less extreme than their current ones. However, these trends are skewed by the fact that other sites with similar climates did not show the same patterns. The OBJ campground site,

which was a relatively wet site showed more growth during the wet years, and the dry Copper Creek II (high elev.) site seemed to prefer growing more during the dry years. Further, there were sites which occurred in the middle of the climate scale, such as Washington Gulch Downhill, Schofield Pass, and the lower Red Rock site, that did not show any preference for either of the climate periods. These results both support and help reject both of the climate envelope hypotheses.

Some of the sites at the warmer end of the climate distribution seemed to favor the wetter period, which would support the single-envelope hypothesis, as does the few sites on the colder end of the distribution that showed more growth during the warmer period. This was expected in the single-envelope case, because it is assumed that populations on the edges of the distribution are not at their climatic optimum, and that any change in climate away from their current would benefit them. This hypothesis is also supported by the fact that some of the interior populations showed no preference for either the wet or dry years.

While there are some weak patterns visible from this data suggesting a single-climate envelope, the alternative hypothesis can also be argued for. It is assumed that if there exist multiple climate envelopes for subalpine fir tree populations, then all of the populations would react differently and unpredictably to warming. This is because they are all assumed to currently be at their respective climatic optimums. There was a lot of variability in how the sites reacted to warmer climate, which supports the multiple-envelope hypothesis.

There may be characteristics about sites that affect the degree of which differential snowmelt date affects conifer growth. This study has shown that both climate

envelope hypotheses may be apparent in this system. Perhaps more light may be shed on this issue with the sampling of more sites. It is also possible that some of the sites, especially those that were geographically closer to each other, shared a climate envelope while others were distinct. While the results of this study may seem inconclusive, it leads to more questions about the dynamics of conifer-dominated ecosystems and how they will change in the presence of global warming.

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