

The effects of drought on subalpine floral community diversity

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Abstract

Global climate change is a threat to ecosystems globally. In subalpine environments, one of the most notable effects of climate change is more frequent and intense droughts. Understanding how this is affecting subalpine plant communities is crucial in understanding how the entire ecosystem is being impacted and can enhance our understanding of how abiotic factors determine flowering plants' habitat ranges. Furthermore, as drought becomes more common across the Western United States, a better understanding of how floral species will respond to decreased water availability will be crucial in designing sustainable urban landscapes. This study investigates the impact of drought on floral community diversity and abundance in the Rocky Mountains in Colorado. I predict that during years of drought community diversity metrics (species richness, Shannon diversity, and evenness) and overall flower abundances will be lower because of the decreased availability of water. I predict these changes will be seen most drastically at higher elevations where climate change induced effects are more extreme. I addressed this by using a data set spanning six years (2016-2021), with three drought years and three non-drought years of data. This research can be used to aid our ability to predict how plant communities will respond in the face of ongoing climate change, as well as to inform efforts to create self-sustaining plant communities in urban landscapes.

1. Introduction

Climate change is impacting nearly every environment across the globe, but in very different ways. Subalpine environments are particularly sensitive to climate change because of their unique adaptations to microclimatic conditions and high elevations (Engler et al., 2011). One of the biggest impacts of climate change in subalpine and alpine regions is drought (Mukherjee et al., 2018). Changing climate patterns and the resulting increased temperatures cause earlier snowmelt which in turn leads to summer drought. The subalpine plant communities are more sensitive to climate change because the effects of abiotic factors, like moisture, are more intense than biotic factors at higher elevations (Korner and Miglietta, 1994). As time goes on, scientists expect to see a reduction in the duration of snow cover induced by increased temperatures causing the zero-degree isotherm to be displaced to higher elevations (Beniston, 2003). The zero-degree isotherm is the elevation in which the temperature is at zero degrees Celsius, or the freezing point, and this means the freezing point is slowly moving up in elevation due to climate change. In flowering communities, the effects of drought on species richness and phenology have begun to be addressed, but the field is still lacking a comprehensive understanding of community level changes over time. A reduction in water availability will likely affect photosynthetic rates of plants, leading to less resources being available for their investment in reproduction and flowers (Phillips et al., 2018). This could potentially affect the outcome of competitive interactions between flower species, and therefore change floral community composition and diversity. This research will show the implications of climate change induced drought on subalpine plant communities. This is important for making predictions of what plant community changes, health, and interactions will look like in the future.

Previous studies have looked at the impacts of climate change, typically by experimentally inducing drought conditions, on flower communities by assessing species richness and abundance, but there is a lack of ‘natural experiments’ that leverage datasets on floral communities spanning years of climate change induced drought. Studies have found that experimentally induced drought led to fewer resources available to the plant, leading to less investment in reproduction and a reduction in number of flowers produced (Phillips et al., 2018). Similarly, it was found that experimentally induced drought caused physiological stress on plants resulting in plants that were smaller, produced lower numbers of flowers, and showed decreasing flower size (Kuppler et al., 2021). Additionally, the phenology of reproduction in plants has evolved to rely on environmental cues (Inouye, 2008). David Inouye studied patterns of earlier snowmelt and more frequent spring frosts due to climate change and their impacts on phenology and floral abundance in subalpine communities (Inouye, 2008).

By assessing how a plant community responds to drought, we can begin to understand what limits of environments and conditions can be tolerated, or the niche breadth, by the species that make up that community. Tied into this concept is how sensitive or insensitive that community is to changes in environment. Because the severity and frequency of droughts caused by climate change in subalpine environments is increasing, floral communities are changing in unknown ways. By beginning research on plant community composition changes we are also beginning to better understand their sensitivity to environmental change and water limitations. Additionally, flowers provide important resources for pollinators (Phillips et al., 2018). When drought imposes potentially severe consequences on floral plant communities, it also threatens those pollinators that depend on them.

Healthy floral plant communities not only offer benefits to the surrounding ecological systems, but to the humans that utilize them as well. Investigating the potential impacts on floral community diversity from drought has important implications on how humans will view and use those communities in the future. Water-intensive gardens have become the primary form of landscaping in most urban areas. This form of landscape architecture is expensive, inefficient, and does not contribute to the health of the surrounding ecosystem. More research is needed on what flowers will naturally be well-suited to thrive under climate change scenarios in subalpine regions. If we can better understand how the floral community's diversity and composition will change in response to drought, we can begin to plan landscaped areas that will survive future droughts and serve as more beautiful, efficient, and healthy statements in our urban areas.

By comparing years of drought and non-drought, this study analyzes the impacts of a powerful effect of climate change, drought, on a subalpine floral community by assessing changes in flower species richness, abundance, evenness, and diversity across three sites during six years (2016-2021) encompassing three severe drought events. I hypothesize that floral community diversity metrics (species richness, evenness, and diversity) will decrease during the drought years compared to non-drought years because the decrease in water availability will lead to a decrease in resources available to the community. I also hypothesize that the impacts of drought will be more intense at higher elevation sites than lower elevation sites because high elevation sites are more sensitive to abiotic factors like moisture level.

2. Methods

(a) Study area and site selection

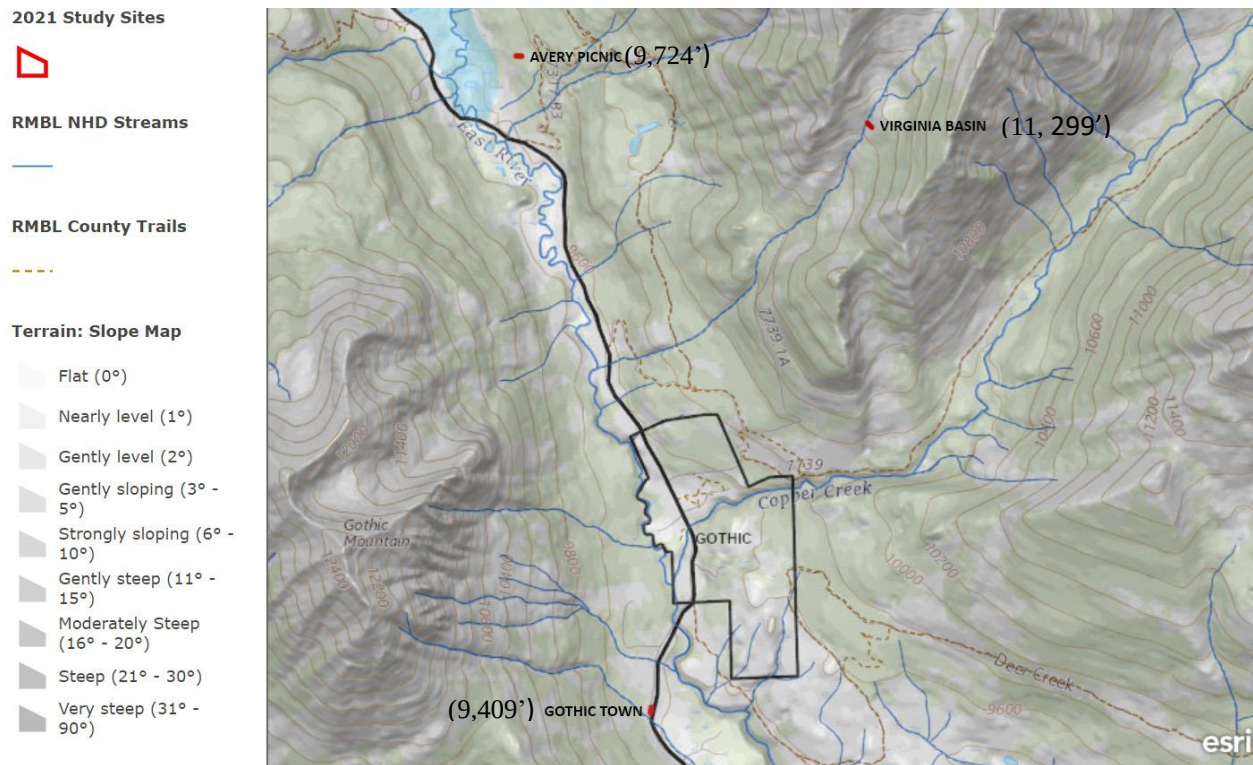


Figure 1. The three sites used for data collection within the Upper East River Valley in Colorado. The sites are outlined in red with Gothic Town at 9,409 feet elevation, Avery Picnic at 9,724 feet elevation, and Virginia Basin at 11,299 feet elevation.

I worked with three sites within the upper East River Valley in Colorado (Figure 1). The sites all surround the Rocky Mountain Biological Laboratory (38°57.50 N, 106°59'.30 W, 9,514 feet above sea level). The sites are Gothic Town (GT), Avery Picnic (AP), and Virginia Basin (VB). Gothic Town represents the lowest elevation site at 9,409 feet, Avery Picnic represents the mid-elevation site at 9,724 feet, and Virginia Basin represents the high elevation site at 11,299 feet. All three sites represent subalpine environments with varying floral communities.

(b) Data collection

Weather data documenting snow totals in centimeters was collected by Billy Barr at the Rocky Mountain Biological Laboratory in Gothic, Colorado for the years from 2016 to 2021. The data in Table 1 clearly shows the winters of 2018, 2020, and 2021 as the drought years defined by low snow total mean (Billy Barr, personal data). The snow totals and snowmelt date have been found to be the most important indicator for drought because plants respond to snowmelt early in the growing season before severe soil dehydration occurs later in the growing season (Vorkauf, M., Kahmen, A., Körner, C. *et al.*, 2021). Therefore, this study used snowmelt totals for the previous winter to determine drought status for the following summer growing season.

Year	Total Snow Mean (cm)	Summer Drought (Y/N)
2016	380	N
2017	548	N
2018	251	Y
2019	440	N
2020	300	Y
2021	298	Y

Table 1. Total snow means measured in centimeters for the winter seasons, defined as the time from November 1st to April 30th, between 2016 and 2021. The drought designation is for the resulting summer drought season after snowmelt occurs in spring. Drought years are bolded.

I collected data during the 2021 summer growing season and combined this with previously collected data from 2016-2020 (Brosi Lab, unpublished data). Floral community data was collected in the form of plant identifications and floral counts. Approximately once per week the three sites were visited and plants that were in bloom were identified and counted. Each site contains four 20x1 meter transects that were used to collect the data. In total there are three years

of data representing a drought year (2018, 2020, and 2021) and three years of data representing a non-drought year (2016, 2017, 2019).

(c) Data analysis

The data was statistically analyzed using ecological diversity metrics for each plant community at the three sites. These metrics were calculated at one-week intervals for each community using R Studio (RStudio Team (2020). RStudio: Integrated Development for R. RStudio, PBC, Boston, MA, <http://www.rstudio.com/>). Abundance was calculated as cumulative flower heads in a site regardless of species, and species richness (S) was measured using raw counts of species present. To quantify diversity, we used the Shannon Diversity Index (H), which considers the number of species that exist within the sample and the relative number of individuals of each species. For evenness, we used Pielou's Evenness (J) which describes how evenly the species are distributed across the community. Next, we used linear regression to test for relationships between our dependent variables (abundance, species richness, evenness, and diversity) and our independent variables (drought versus non-drought years). Species richness, Pielou's Evenness, and the Shannon Diversity Index were all normally distributed along the model, but abundance was not normally distributed, so the data was log transformed to give it a more normal distribution.

3. Results

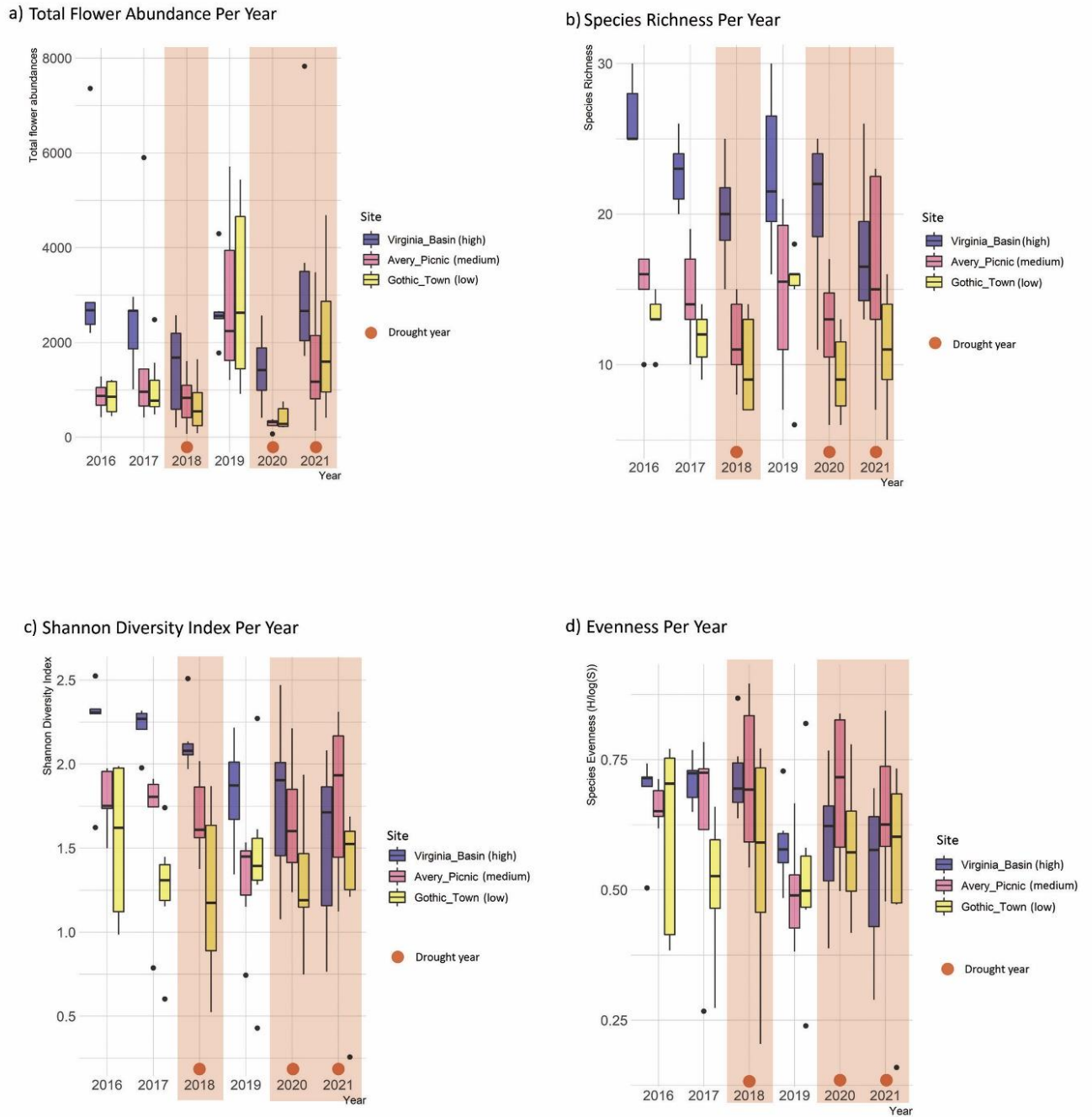


Figure 2. The effect of drought on diversity metrics and abundance

Figure 2. The abundance, species richness, Shannon Diversity Index, and species evenness for 2016-2021 at Virginia Basin, shown in purple, Avery Picnic, shown in pink, and Gothic Town, shown in yellow. The three drought years, 2018, 2020, and 2021, are demarcated by orange bars.

When looking at all three study sites together it is clear that drought has a significant negative effect on species richness and abundance, but the diversity and evenness results were mixed, because of an increase in evenness at Avery Picnic and a decrease in diversity at Virginia Basin. In Figure 2a drought has a significant negative affect on abundance at Gothic Town, Avery Picnic, and Virginia Basin. Figure 2b shows that drought decreased species richness at Virginia Basin and Gothic Town, but not at Avery Picnic. Drought only causes decreased diversity at Virginia Basin, but not at Avery Picnic or Gothic town, as seen in Figure 2c. According to Figure 2d drought increased evenness at Avery Picnic and had no effect on Gothic Town or Virginia Basin.

a) Abundance

Site	Estimate	Standard Error	P Value	Significance
Virginia Basin	-0.52	0.24	0.04	Significant
Avery Picnic	-0.82	-2.47	0.02	Significant
Gothic Town	-0.62	0.29	0.04	Significant

b) Species Richness (S)

Site	Estimate	Standard Error	P Value	Significance
Virginia Basin	-4.52	1.45	0.004	Significant
Avery Picnic	-1.31	1.51	0.39	No effect
Gothic Town	-2.73	0.98	0.01	Significant

c) Shannon Diversity Index (H)

Site	Estimate	Standard Error	P Value	Significance
Virginia Basin	-0.26	0.14	0.07	Near Significant
Avery Picnic	0.17	0.12	0.17	No effect
Gothic Town	-0.10	0.14	0.47	No effect

d) Evenness (J)

Site	Estimate	Standard Error	P Value	Significance
Virginia Basin	-0.04	0.04	0.33	No effect
Avery Picnic	0.10	0.05	0.05	Significant
Gothic Town	0.02	0.05	0.71	No effect

Table 2. Significance values for each diversity metric.

4. Discussion

Overall, this study found that our predictions were partially supported. The results supported the hypothesized reduction in abundance and species richness due to drought, but the results did not support the hypothesized reduction in evenness and diversity. The only effect of drought on evenness was an increase at Avery Picnic, which was unusual and unexpected. Finally, the results supported the hypothesis that drought would have the biggest impact at Virginia Basin because it is the highest elevation site. Virginia Basin saw the most changes caused by drought: a decrease in abundance, species richness, and diversity. When taken together, our results indicate that drought can significantly decrease flowering abundance and species richness and these effects are more intense at high elevations.

The results at Avery Picnic were the most unusual and are worthy of reviewing. Drought was found to cause a decrease in abundance and an increase in evenness and had no effect on richness or diversity at Avery Picnic. One possible explanation for the increase in evenness is that drought may have caused one or more of the dominant species to be compromised, which could allow for other, less significant species to prosper, and therefore increase the evenness of species in the community. The problem with this explanation is that it doesn't account for the lack of increased evenness at the other two sites. Some interesting patterns can be seen between the diversity metrics when looking at the Avery Picnic results and the equation for evenness. Drought caused a lower abundance of all species at the site, but there was no species richness change, so no species were lost due to drought. These two factors contributed to the increase in evenness. The equation for evenness is the Shannon Diversity Index (H) over the natural log of species richness (S). When evenness went up, but richness stayed the same, it must mean that the

Shannon Diversity Index (H) is influenced, or increased, when evenness increases. Additionally, Avery Picnic contained slightly different microclimatic conditions that may have impacted some of these metrics. It was the most lush and wet site within the study. The foliage would often remain very wet until mid-day, where the other sites would usually be dry by around 10:00 am. This extra moisture could have conflicted with the drought conditions and caused some of these unique results.

Next it is important to discuss the increased impact of drought on high elevation sites like Virginia Basin in the case of this study. As mentioned earlier in this paper, high elevation sites have been found to be more sensitive to abiotic factors like water availability (Korner and Miglietta, 1994). The results of this study show that a change in elevation of 1,575 feet between the mid- and high-elevation sites led to more significant changes in the diversity metrics during years of drought at Virginia Basin, the high elevation site. This information has important implications for the future of our sub-alpine environments. In a study that involved induced carbon dioxide increases there was a significant elevational signal in the temperature and precipitation changes in an alpine region, with more significant increases at higher elevations. The elevational signal was more pronounced in surface warming during the winter and spring seasons since it is associated with melting snowpack. The researchers in this study therefore concluded that temperature changes at higher elevations could be used as an early detection method for climate change (Giorgi et al., 1997). What the elevational signal in this study means is that the degree of temperature change is highly dependent on the elevation level. The research by Giorgi et al. is pertinent to this study because it discusses how elevational signal for temperature changes during the winter and spring relate to snowpack levels. This translates into

the resulting summer drought that is discussed in this study. When there are more pronounced temperature changes at high elevations due to decreasing snowpack, you are likely to see changes in plant community diversity metrics during the following summer. This shows how important it is to understand the changes happening to plant communities at high elevations, as it can help us measure and predict signs of climate change progression.

It is also important to consider some confounding factors that may have affected the results in this study. First, there were likely unique factors at each site that may have impacted the diversity metric calculations that were not considered in this study. These may include microclimate conditions, temperature variations, aspect variations, unique species interactions, and more. Secondly, there were some distinctive climate patterns within the data set that may have influenced the results. 2018 was the driest year within the data set and it was immediately followed by the wettest year in 2019. It is unknown how the transition from dry extreme to wet extreme impacted the plants present at the three study sites. Additionally, 2021 was qualified as a drought year because the total snow mean in the winter was only 298 centimeters according to Table 1, but the winter was followed by an uncharacteristically rainy summer season. This may have changed the growing period, the amount of resources available for the plant, or the number of species present which could all influence the diversity metrics. More research would need to be completed on the specific interactions between plant communities and the climate patterns to fully understand the potential impacts.

Overall, this study demonstrates some implications of climate-change-induced drought on subalpine plant communities. This is important for making predictions about plant community changes, health, and interactions moving into the future. And more broadly this research can help us better understand plant sensitivity to environmental conditions and water limitations. Additionally, the information gleaned from this project has many real-world applications. It can be used for better understanding biology, ecology, conservation, and design. In relation to urban landscape design, if we can begin to understand how premature snowmelt and the resulting summer drought is changing natural plant diversity, then we can begin to incorporate this knowledge into urban landscape architecture to create more holistic systems. The current, prominent form of urban landscaping are water intensive gardens that are expensive, inefficient, and don't contribute to the overall health of the surrounding ecosystems. The information gained from this research can help to design more place-specific, efficient, sustainable, and healthy landscapes in urban environments. This study should be continued to better understand how climate change is evolving in subalpine environments in the future and to better track the other conditions that may be affecting plant community diversity changes.

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